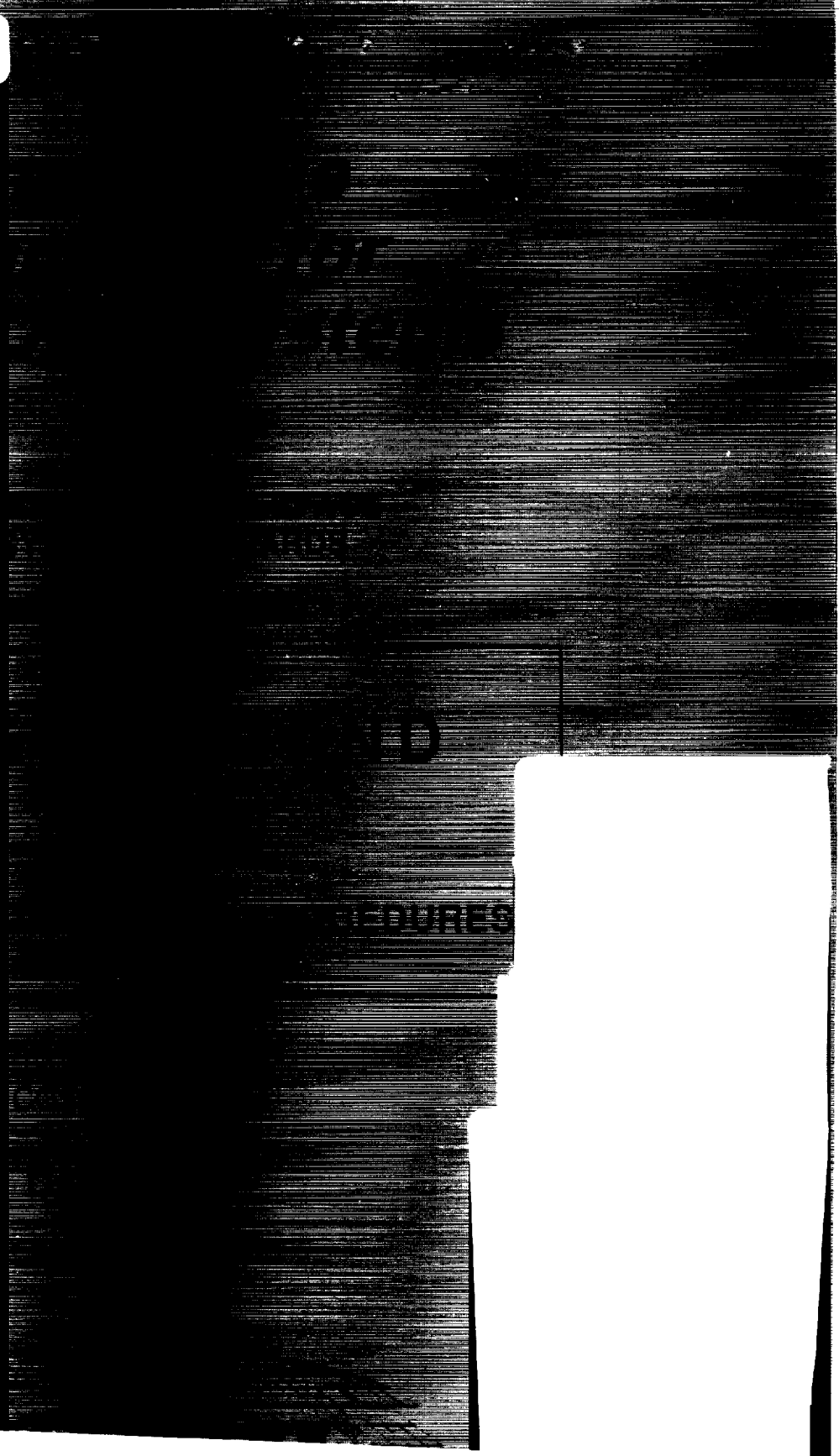

NOTICE TO READERS

Three COPs are defined in the parent Recommendation (Telecommand, Part 2: Data Routing Service, 1987). Only two of these (COP-0 and COP-1) have been developed and specified to the level of detail needed for implementation. Detailed specifications for COP-0 and COP-1 are contained in the attached draft of the Recommendation.

However, your attention is called to the fact that only COP-1 has been simulated, tested, supported with VLSI chip sets for flight applications, supported with portable ground software, and selected for use on upcoming flight projects in both ESA and NASA.

No flight users have been firmly identified for COP-0 , nor does future use seem likely. Therefore, unless comments are received by the Secretariat from agencies requesting the retention of COP-0, the Committee plans to withdraw it at the next revision.

COP-2 (Selective Repeat of Telecommand Frames) has not yet been developed to the level of detail necessary for implementation or for this specification. It is believed that the needs of missions previously thought to be candidates for a selective repeat protocol at the Data Routing (Frame) level may be better served either by use of the standard COP-1 protocol or by a to-be-developed selective repeat protocol at the Data Management (Packet) level (Telecommand, Part 3) instead. Therefore, unless comments are received by the Secretariat from agencies requesting the retention of COP-2, the Committee plans to withdraw it at the next revision. If it is decided its development should continue but is not completed when Part 2.1 is ready for approval, it will appear as a "To Be Supplied" item and will not cause delay in approving the rest of the Recommendation. The Recommendation may be reissued in a later year to add the protocol when it is completed.

Normally, Red Books are accompanied by a request for official agency review and approval. The Committee believes that this Red Book is now in a relatively stable, mature state, since it has been developed in close coordination between ESA and NASA. In particular, the definition of COP-1 is essentially the same as that being adopted in the ESA Telecommand Standard. Nevertheless, because it is a highly complex and important Recommendation, the Committee believes the agencies should have an extended period to understand, validate and test the protocol in their own environment, if they desire, before approval. Therefore, only informal technical comments are solicited from the agencies during the next 6 months or so. Comments should be directed to the Telecommand Working Group Chair: Kathy Moyd, NASA/JPL, Mail Stop 301-280, 4800 Oak Grove Drive, Pasadena, CA 91109;
FAX +1 818 354 9068;
TELEMAIL: (C:USA,ADMD:TELEMAIL,PRMD:NASAMAIL,O:NASA,UN:KMOYD).

It is not planned to materially change the specification (except for possible withdrawal of COP-0 and/or COP-2 and transfer of some of the explanatory information to an updated Telecommand Green Book) unless the change is justified. It is expected that the final Recommendation will be up for official approval, most probably in time for finalization at the Spring 1992 Plenary meeting.

AUTHORITY

Issue:	Red Book, Issue-4
Date:	January 1991
Approval	CCSDS Management Committee

(WHEN THIS RECOMMENDATION IS FINALIZED IT WILL CONTAIN THE FOLLOWING AUTHORITY STATEMENT:)

This Recommendation reflects the consensus technical agreement of the following member Agencies of the Consultative Committee for Space Data Systems (CCSDS):

TBS

The following observer Agencies also concur with this Recommendation:

TBS

This Recommendation is published and maintained by:

CCSDS Secretariat
Communications and Data Systems Division (Code-OS),
National Aeronautics and Space Administration
Washington, DC 20546, USA

STATEMENT OF INTENT

(WHEN THIS RECOMMENDATION IS FINALIZED, IT WILL CONTAIN THE FOLLOWING STATEMENT OF INTENT:)

The Consultative Committee for Space Data Systems (CCSDS) is an Organization officially established by the management of member space Agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed RECOMMENDATIONS and are not considered binding on any Agency.

This RECOMMENDATION is issued by, and represents the consensus of, the CCSDS Plenary body. Agency endorsement of this RECOMMENDATION is entirely voluntary. Endorsement, however, indicates the following understandings:

- Whenever an Agency establishes a CCSDS-related STANDARD, this STANDARD will be in accord with the relevant RECOMMENDATION. Establishing such a STANDARD does not preclude other provisions which an Agency may develop.

- Whenever an Agency establishes a CCSDS-related STANDARD, the Agency will provide other CCSDS member Agencies with the following information:

  -- The STANDARD itself.

  -- The anticipated date of initial operational capability.

  -- The anticipated duration of operational service.

- Specific service arrangements shall be made via memoranda of agreement. Neither this RECOMMENDATION nor any ensuing STANDARD is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this Recommendation will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or, (3) be retired or cancelled.

FOREWORD

This document, which is a technical Recommendation prepared by the Consultative Committee for Space Data Systems (CCSDS), is intended for use by participating space Agencies in their development of space telecommand systems.

This Recommendation allows the implementing organizations within each Agency to proceed coherently with the development of compatible Standards for the flight and ground systems that are within their cognizance. Agency Standards derived from this Recommendation may implement only a subset of the optional features allowed herein, or may incorporate features not addressed by the Recommendation.

The *Recommendation for Telecommand:Part 2: Data Routing Service* (Reference [3]) defines the standard data structures and data communication procedures to be used by conventional missions within the intermediate telecommand system layers. The Command Operation Procedures form a subpart of the Data Routing Service and are described in Reference [3]. This Recommendation contains the definition of the Command Operations Procedures in the form of state tables at the level of detail necessary to allow cross support. It is assumed that the reader is familiar with the terminology and data structures defined in Reference [3].

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommendation is therefore subject to CCSDS document management and change control procedures which are defined in Reference [1].

DOCUMENT CONTROL

ISSUE	TITLE	DATE	STATUS
Red Book, Issue-1	Recommendation for Space Data System Standards: Telecommand, Part -2 Data Routing Service, Annex-C	July 1985	Name changed, superseded
Red Book, Issue-2	Recommendation for Space Data System Standards: Telecommand, Part 2.1, Command Operation Procedures, Detailed Specifications and State Matrices	April 1986	Superseded
Red Book, Issue-3	Recommendation for Space Data System Standards: Telecommand, Part 2-1, Command Operation Procedures	April 1990	Superseded
Red Book, Issue-4	Recommendation for Space Data System Standards: Telecommand, Part 2-1, Command Operation Procedures	January 1991	Current Issue

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REFERENCES

[1] "Procedures Manual for the Consultative Committee for Space Data Systems", CCSDS A 00.0-Y-4.0, Yellow Book, Issue 4, Consultative Committee for Space Data Systems, September 1990 or later issue.

[2] "Telecommand, Part 1: Channel Service, Architectural Specification", Recommendation CCSDS 201.0-B-1, Blue Book, Issue 1, Consultative Committee for Space Data Systems, January 1987 or later issue.

[3] "Telecommand, Part 2: Data Routing Service, Architectural Specification", Recommendation CCSDS 202.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue

[4] "Telecommand, Part 3: Data Management Service, Architectural Definition", Recommendation CCSDS 203.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

[5] "Telecommand, Summary of Concept and Service", CCSDS 200.0-G-6, Issue 6, Green Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Recommendation contains the detailed specification of the logic required to carry out the Command Operations Procedures of the Transfer Layer.

The *Recommendation for Telecommand: Part 2, Data Routing Service*, (Reference [3]) contains the standard data structures and data communication procedures used by the intermediate telecommand system layers (the Transfer and Segmentation Layers). In particular, it contains a brief description of the Command Operations Procedures (COP) within the Transfer Layer. This Recommendation contains the detailed definition of the COPs in the form of state tables, along with definitions of the terms used. It is assumed that the reader of this document is familiar with the data structures and terminology of Part 2.

In case of conflict between the description of the COPs in Part 2 (Reference [3]) and in this Recommendation, the definition in this Recommendation will take precedence. In particular, this document supersedes Section 4.3.3.1 through 4.3.3.4 of Part 2.

1.2 APPLICABILITY

This Recommendation serves as a guideline for the development of compatible internal Agency standards in the field of spacecraft commanding. This Recommendation is not retroactive, nor does it commit any Agency to implement the recommended telecommand concepts at any future time. Nevertheless, all CCSDS Agencies accept the principle that all future implementations of telecommand which are used in cross-support situations will be based on this Recommendation.

The CCSDS has developed a layered concept for future spacecraft telecommanding, which is summarized in Reference [5] and defined in the *Telecommand Recommendations Part 1: Channel Service* (Reference [2]), *Part 2: Data Routing Service* (Reference [3]) and *Part 3: Data Management Service* (Reference [4]). Standard services are defined within each layer, and Agencies will be encouraged to develop corresponding facilities to provide these services in support of Projects. This Recommendation is applicable only to those Projects which are compatible with the Transfer Layer as defined in the *Recommendation for Data Routing Service* (Reference [3]).

Where preferred options or mandatory capabilities are clearly indicated herein, the indicated sections of the specification must be implemented when this Recommendation is used as a basis for cross-support. Where optional subsets or capabilities are allowed or implied in this specification, implementation of these options or subsets is subject to specific bilateral cross-support agreements between the Agencies involved.

The recommendations in this document are to be invoked through the normal standards programs of each member Agency, and are applicable to those missions for which cross-

support based on capabilities described in these recommendations is anticipated.

No later than five years from its date of issue, this Recommendation should be reviewed by the CCSDS Agencies to determine whether it should: 1) remain in effect without change; 2) be changed to reflect the impact of new technologies, new requirements, or new directions; or 3) be retired or cancelled.

1.3 STATE TABLE FORMAT

This document contains the state tables for each of the TC COPs. For each FOP or FARM, the State Table shows the various "STATES" (columns) in which the process might be at a given time, and the "EVENTS" (rows) which cause "ACTIONS" and/or STATE changes. The ACTION and/or STATE change appropriate to the occurrence of a particular event, when the processes are in a particular STATE, is shown at the intersection of the respective row and column. STATE transitions are indicated by STATE NUMBERS in parenthesis; thus "(S2)" indicates "go to STATE number 2". See Figure 1.1.

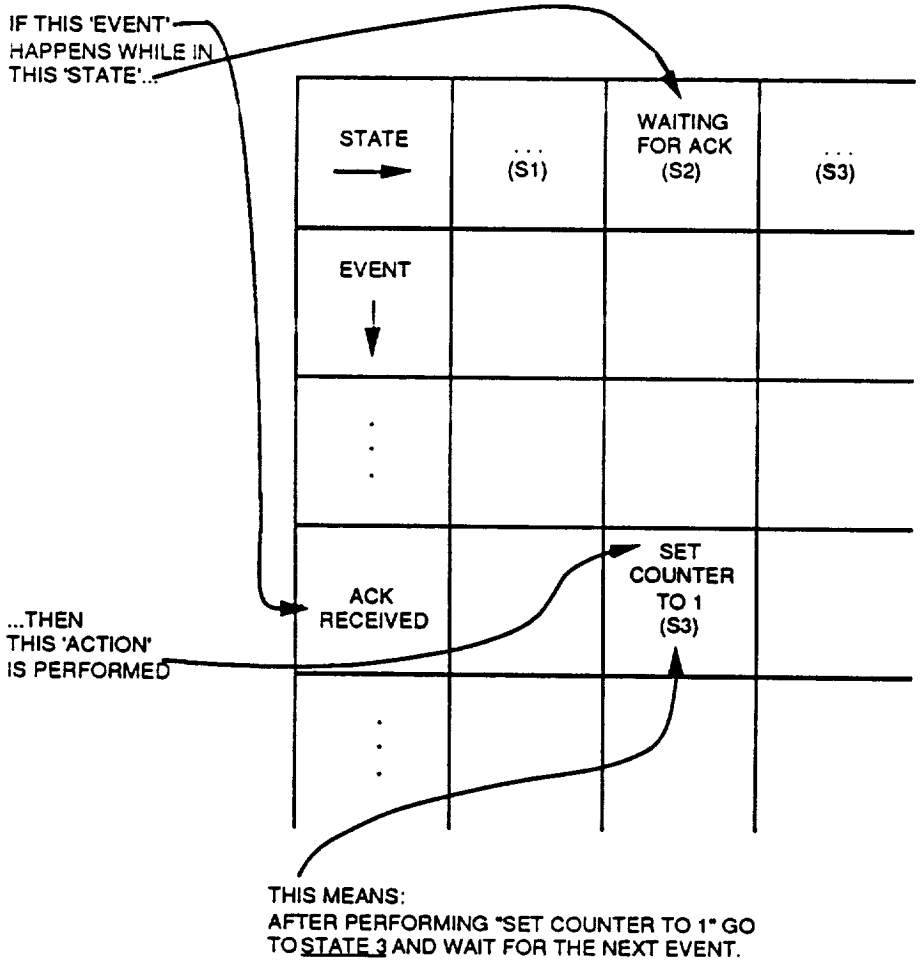

FIGURE 1.1: State Table Format

Note: The table describes the processing for one independent virtual channel.

1.4 OVERVIEW OF COPS

1.4.1 COP-0

COP-0 is a closed-loop telecommanding protocol within which control of sequentiality is provided by the sending-end FOP rather than the receiving-end FARM. The FARM sends down a count of the valid Type A commands received on the Virtual Channel. In order to ensure the delivery of frames in order, with no omissions, the spacecraft must stop accepting Type A frames on all Virtual Channels using COP-0 if an invalid frame is received or if there is a problem with the physical channel which might cause frames to be lost. In such a case, the Lockout Flag in the CLCW is set. The ground will then use the counter value in the CLCW to determine how many frames have been accepted and therefore from what point retransmission should occur. Because the end of a CLTU causes a decoder failure, all frames to be transmitted before any acknowledgements are received on the ground must be included in the same CLTU. The start of a new CLTU also unlocks FARM-0 on all Virtual Channels.

Valid Type B frames (i.e., bypass frames) will always be accepted. There are no control commands (Type BC) for COP-0.

1.4.2 COP-1

COP-1 is a closed-loop telecommanding protocol which utilizes sequential ("go-back-n") retransmission techniques to correct TC Frames which were rejected by the spacecraft because of error. COP-1 allows Type-A TC Frames to be accepted by the spacecraft only if they are received in strict sequential order and their contents can be immediately passed on to the layer above.

Within COP-1, control of sequentiality is provided by the FARM instead of the FOP, and therefore frame sequence numbering is explicit. The Frame Sequence Number must be present in each frame, and Type-A frames must be transmitted by the FOP with their numbers arranged in strict upcounting order. If one or more frames are missed, retransmission is initiated either in response to a Retransmit Flag in the CLCW or a timeout on the ground. Window mechanisms on the ground and spacecraft prevent a new frame with the same sequence number as that of a missing frame from being accepted.

Valid Type B frames (i.e., bypass frames) will always be accepted.

2 COP-0

COP-0 is a closed-loop telecommanding protocol within which control of sequentiality is provided by the sending-end Frame Operation Procedure (FOP) rather than the receiving-end Frame Acceptance and Reporting Mechanism (FARM); therefore numbering of frames by the FOP is unnecessary. The FRAME SEQUENCE NUMBER field must be present in every TC Frame, but since it is unused by the FARM its contents are set by convention to value "all zeros".

FOP-0 accepts batches of user data in the form of Frame Data Units (FDU) from the layer above, formats each FDU into a TC Frame and passes the batch of frames to the lower layer for transmission within a single Command Link Transmission Unit (CLTU). The batches may range in size from 1 to 256 FDUs (i.e., the resulting CLTU may contain from 1 to 256 TC Frames.). The content of the Frame Data Unit will be a TC segment if the interfacing higher layer is the Segmentation Layer, one TC Packet[1] if the higher layer is the Packetization Layer or a user-defined data unit if the higher layer is neither of these.

FARM-0 submits each received frame to the standard Frame Validation Check that is defined in Part 2, Section 4.3.2. Any Type-B frame which passes the validation check is distributed on its appropriate Virtual Channel and the FARM-B COUNTER is incremented. Any Type-A frame which passes the validation check is distributed on its appropriate Virtual Channel and the FARM-A COUNTER is incremented, unless the FARM is in the Lockout State.

Any Type-A or Type-B frame which fails the Frame Validation Check shall be discarded, and FARM-0 shall immediately enter LOCKOUT to prevent the acceptance of further Type-A frames on ANY Virtual Channel. This is necessary since the FARM has no knowledge of the Type or Virtual Channel assignment of the erroneous frame; therefore all Virtual Channels must be locked out to preserve sequentiality. Any subsequent Type-B frame which passes the Frame Validation Check will be processed normally. The LOCKOUT mode for Type-A frames will remain in effect until it is cleared by reception of the start sequence at the beginning of a new CLTU. Receipt of a valid start sequence allows resumption of operation on all Virtual Channels. To avoid the inadvertent resetting of a Lockout condition, FOP-0 must wait until all frames of a CLTU have been received and acknowledged before initiating a new CLTU. This send-and-wait technique makes COP-0 inefficient in long delay or high data rate applications. It is designed primarily for low-rate commanding of earth-orbiting spacecraft without the use of data relay satellites.

In the event of an observed LOCKOUT, FOP-0 ceases the transmission of frames to the layer below, calculates the number of Type A frames which were accepted by the FARM prior to the failure (by subtracting the initial value of the FARM-A COUNTER from its current value) and "goes-back-n" to initiate a new CLTU, retransmitting the unacknowledged Type A frames from the point of failure. Retransmission is not provided for Type B frames.

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[1] The current issue (Issue 1) of the CCSDS Recommendation for Telecommand, Part 2: Data Routing Service (Reference [3]) allows only one TC Packet per FDU. The technical experts have agreed in principle that multiple complete Packets should be allowed and this is expected to be incorporated in the next issue of Reference [3].

"goes-back-n" to initiate a new CLTU, retransmitting the unacknowledged Type A frames from the point of failure. Retransmission is not provided for Type B frames.

Acceptance of a Type-A frame on a particular Virtual Channel by FARM-0 causes the following actions:

A. The value of the FARM-A COUNTER shall increment by one, and

B. The CLCW parameters for that Virtual Channel shall be updated.

Receipt of a valid Type-B frame on a particular Virtual Channel by FARM-0 causes the following actions:

C. The FARM-B COUNTER shall increment by one, and

D. The CLCW parameters for that Virtual Channel shall be updated.

Since any frame which fails a Frame Validation Check will cause FARM-0 to enter LOCKOUT and reject all subsequent Type-A frames REGARDLESS OF THEIR VIRTUAL CHANNEL, any error in any frame will effectively stop the entire flow of telecommands on all Virtual Channels which use COP-0 until corrected.

The COP-0 protocol is described by means of state tables, one at each end for each Virtual Channel. The state table for FOP-0 is given in Table 2.1; the state table for FARM-0 is given in Table 2.2. A description of how to read the tables is given in Section 1.3.

2.1 STATES

ACTIVE

FOP in nominal status; ready to accept FDUs from upper layers and transmit them.

AWAITING ACKNOWLEDGEMENT

FOP is waiting for receipt of previously transmitted Type A frames to be confirmed by receipt of CLCWs. No additional frames can be transmitted.

LOCKOUT

An invalid frame has been received or a problem has occurred on the physical link. The FARM rejects all subsequent Type-A frames until reset by the start of a new CLTU.

OPEN

FARM is ready to accept frames. No anomalous conditions exist.

2.2 VARIABLES

CLCW

Command Link Control Word

CLCW Flag

The logical "OR" of all flags in the CLCW used by COP-0: NO-RF-AVAIL, NO-BIT-LOCK, LOCKOUT.

CLTU

Command Link Transmission Unit

FARM-A Counter

An 8-bit counter, reported in the CLCW, which increments once for every Type-A frame that is accepted by the FARM on a particular Virtual Channel.

FARM-B Counter

A 2-bit counter, reported in the CLCW, which increments once for every Type-B frame that is accepted by the FARM on a particular Virtual Channel.

Lockout Flag

The CLCW field that shows whether the receiving end is in the Lockout state.

N

Used as a "local variable" in the state tables to show that the number of frames discussed in an action is the same as the number of frames mentioned (as N) in an event; N has no significance outside the state tables.

New Count

The command counter (FARM-A COUNTER) value, and hence the NN(R) Value which should be reached after all frames of a COP-0 CLTU have been received and accepted at the receiving end FARM.

N(R)

FARM-A COUNTER value reported in a CLCW.

NN(R)

Latest value of N(R) recorded at the sending end FOP for a given channel.

Sent Queue

The FOP-maintained list of Type A frames which have been transmitted but not yet acknowledged.

The meaning of "acknowledged" is:

Each increment of the FARM-A counter acknowledges one Type-A frame in the current CLTU, in sequence, starting with the first. Thus if NN(RI) is the initial value of N(R) as recorded by the FOP before transmission of the CLTU, and NN(R) is the latest reported value, then the first NN(R) - NN(RI) frames of the CLTU have been acknowledged.

Timer

A mechanism for applying the TIMEOUT PARAMETER to assure that the Higher Layer is notified if successful receipt by the spacecraft has not been not verified within a reasonable time.

Transmission_Count

The Transmission_Count is the number of times a frame has been transmitted or retransmitted.

Transmission Limit

The Transmission_Limit is the maximum number of times that a frame may be transmitted. This includes the first transmission and any subsequent retransmissions of the frame.

2.3 ACTIONS

Accept frame

The FARM logic embodied in the state table has determined that a frame has passed the COP acceptance checks. The FARM should deliver the frame under consideration to the receiving end higher layer.

Alert

The FOP should inform the operator or supervising process that some non-nominal event has occurred.

Cancel Timer

"Turn off" a timer that would otherwise, upon expiration, signal that one or more frames failed to arrive and pass validation and acceptance checks at the receiving end.

Dequeue

Remove from the Sent Queue all frames which were acknowledged by the last CLCW, if any. Cancel the timer if all frames are removed from the Sent Queue.

Discard

A frame has failed to pass acceptance checks or the FARM is in a state which will not allow any Type-A-frames to be accepted. Do not accept the frame for delivery, i.e., discard the frame.

Ignore

Take no action; give no response; do not change state.

Report

Place the values of the parameters indicated into a CLCW for transmission to the sending end.

Retransmit

Remove a frame from the Sent Queue, determine if it has been transmitted the maximum number of times allowed, as specified by the value of Transmission_Limit and if not, pass the frame to the lower layer for transmission. If the frame is not rejected by the lower layer, place the frame back onto the Sent Queue pending acknowledgement and restart the Timer.

If the frame is rejected by the lower layer, the FOP attempts to pass the frame for transmission until successful, or until the maximum number of attempts allowed is reached.

If the FOP is unsuccessful in transmitting the frame within the number of attempts allowed, the FOP "alerts" a higher layer (or operator).

Set NEW_COUNT to NN(R) + N

Set the value of this sending end parameter to the sum of the last-received value of the spacecraft command counter (FARM-A Counter), as recorded in NN(R), plus the number (N) of frames to be transmitted in the next CLTU. After transmission, and reception by the FARM, of that CLTU, the command counter, and therefore NN(R), should contain the value of NEW_COUNT.

Transmit

Prepare an FDU for sending (via lower-layer services) to the receiving end. This includes formatting the FDUs as TC frames, setting the value of N(s) in the frame to 0 and starting or resetting a timer. The frame is then passed to the lower layer for transmission. If it is not rejected by the lower layer, the frame is placed on the Sent Queue pending acknowledgement and the Timer is started or restarted. If the frame is rejected by the lower layer service, the FOP attempts to pass the frame until successful or until the maximum number of attempts allowed is reached.

Transmit User Data Type BD frame

This is bypass commanding. The FDU will be formatted and transmitted as a type B command and thus will be accepted and delivered at the receiving end without regard to the value of the Lockout Flag. The frame will not be put on the Sent Queue and no retransmission will occur in case of a FARM-0 Lockout.

Table 2.1 FOP-0 State Table

STATE NAME					ACTIVE	AWAITING ACKNOWLEDGEMENT
Main Feature of State					Ready to transmit	CLTU is being or has been transmitted
State Number					S1	S2
Event Category	**Event Conditions**			**Event Number**		
Report	Valid CLCW with N(R) = NEW_COUNT			E1	Dequeue (S1)	Dequeue (S1)
	Valid CLCW with N(R) ≠ NEW_COUNT	CLCW_FLAG Transition 0 to 0 or 1 to 1 or 1 to 0		E2	Dequeue (S1)	Dequeue (S2)
		CLCW_FLAG Transition 0 to 1	Transmission_Count < Transmission_Limit	E3	Ignore (S1)	Dequeue; Initiate Retransmission of All Frames Remaining on SENT_QUEUE (S2)
			Transmission_Count >= Transmission_Limit	E4	Alert (S1)	Dequeue; Cancel Timer if Running; Alert (S2)
	Invalid COP-0 CLCW Arrives			E5	Ignore (S1)	Alert (S2)
Command Frame Transmission Request Events	Receive Request from Upper Layer	Receive Request to Send 'N' FDUs of User Data	No Bypass	E6	Clear SENT_QUEUE; NEW_COUNT:= NN (R) + N; Initiate Transmission of All N Frames (S2)	Reject (S2)
			Bypass	E7	Clear SENT_QUEUE; InitiateTransmission of User Data Type-BD Frames (S1)	Reject (S2)
Timeout Event	TIMER Expires on Transmitted CLTU			E8	Ignore (S1)	Alert (S1)
Manage-ment Directive Events	Receive Set Transmission_Limit Directive			E9	Set Transmission_Limit (S1)	Set Transmission_Limit (S2)
	Receive Set Timer_Value Directive			E10	Set Timer_Value (S1)	Set Timer_Value (S2)

The "CLCW_FLAG Transition", is a comparison of the newly-received CLCW with the last-received CLCW and is given in the form of the value of the last-received CLCW_FLAG "to" the value of the newly-received CLCW_FLAG. "0 to 0" and "1 to 1" mean there has been no change since the previous report, "0 to 1" means first receipt of a CLCW in which at least one of the flags has been set to 1 (indicating a FARM problem) and "1 to 0" means first receipt of a CLCW in which all previously-set flags have been reset to 0 (indicating the FARM is now ready to resume normal operation).

Table 2.2 FARM-0 State Table

STATE NAME			OPEN	LOCKOUT
Main Feature of State			Normal state to accept frames	Frames not accepted
State Number			S1	S2
Event Type	Event Conditions	Event Number		
Frame Events	Valid User Data Type AD Frame	E1	Accept Frame; Increment FARM_A_COUNTER (S1)	Discard (S2)
	Valid User Data Type BD Frame Arrives	E2	Accept Frame; Increment FARM_B_COUNTER (S1)	Accept Frame; Increment FARM_B_COUNTER (S2)
	Start of CLTU Signal Arrives from Lower Layer	E3	LOCKOUT_FLAG:=0; (S1)	LOCKOUT_FLAG:=0; (S1)
	Invalid Frame, Loss of RF Lock, or Loss of Bit Lock Detected*	E4	LOCKOUT_FLAG:=1 (S2)	Ignore (S2)
Reporting Event	CLCW Report Time Arrives	E5	Report COP-0 CLCW Values (S1)	Report COP-0 CLCW Values (S2)

*NOTE: If the lower layer detects incoming frames that fail validation check, or loss of RF or bit lock, this is signaled to the FARM as Event E4 which drives the FARM into lockout state. This is required by COP-0 to maintain sequentiality.

3 COP-1

NOTE: In this section, although it may be mentioned that COP-1 handles "frames", these are actually partial frames made up of a TC Frame Data Unit (FDU) plus the Frame Header data generated by COP-1. The remainder of the Frame Header will be generated by the Lower Layer. The content of the Frame Data Unit will be the length of the FDU plus a) one TC segment if the interfacing Higher Layer is the Segmentation Layer or b) one TC Packet[1] if the Higher Layer is the Packetization Layer or c) a user-defined data unit if the Higher Layer is neither of these.

COP-1 is just one of the functions performed within the Transfer Layer. It is the first function performed when an FDU is received by the Transfer Layer on the sending end and the last one performed before the FDU is delivered to the Higher Layer on the receiving end. For purposes of defining the interfaces to COP-1, the function following FOP-1 on the sending end will be called "Frame Generation" and the one preceding FARM-1 on the receiving end will be called "Frame Validation Check".

3.1 SERVICES AND PROTOCOLS

3.1.1 SERVICES

COP-1 provides two distinct services to the layer above. These services are:

(a) Sequence-Controlled Service

This service concerns two types of frames:

- AD for frames carrying data from the layer above (TC FDUs)

- BC for the two frames carrying protocol control information for configuring COP-1 ("Unlock" and "Set V(R)")

In COP-1 the Sequence-controlled Service is based on an automatic request for retransmission (ARQ) procedure of the "Go-back-N" type with sequence-control mechanisms both on the ground and onboard the spacecraft and the necessary presence of a standard return data report in the telemetry downlink, the Command Link Control Word (CLCW).

The Sequence-Controlled Service is initiated by means of four distinct "Initiate AD Service Directives" as shown in Table 3.1 (FOP-1 State Table). Two of these directives consist in transmitting one of the two control frames (BC). Each of the two control frames causes a well-defined action in FARM-1, which is then reflected in the CLCW. A timer is used to cause

[1] The current issue (Issue 1) of the CCSDS Recommendation for Telecommand, Part 2: Data Routing Service (Reference [3]) allows only one TC Packet per FDU. The technical experts have agreed in principle that multiple complete Packets should be allowed and this is expected to be incorporated in the next issue of Reference [3].

retransmission of the control frame if the expected response is not received, with a limit on the number of automatic retransmissions allowed before the Higher Layer is notified that there is a problem in initiating the AD Service. The other two directives allow the AD Service to be started without waiting for spacecraft action (although one requires receiving a good CLCW).

Once COP-1 for a particular Virtual Channel has been initialized for an AD service, TC FDUs are inserted into frames and transmitted on that Virtual Channel in the order in which they are presented to COP-1. The retransmission mechanism ensures that:

- No TC FDU is lost
- No TC FDU is duplicated
- No TC FDU is delivered out of sequence.

The AD Service guarantees in-order delivery of TC FDUs on a single Virtual Channel. Because of the possibility of retransmission on only a single Virtual Channel, there is no guarantee that TC FDUs on separate Virtual Channels, each using an AD Service, will be delivered to the Higher Layer in the order initially transmitted.

For the AD Frames, the automatic retransmission procedure makes use of several variables, the most notable being the Receiver_Frame_Sequence_Number, V(R); the Transmitter_Frame_Sequence_Number, V(S); the Next-Expected-Sequence-Number contained in the CLCW ,N(R); and the Frame-Sequence-Number in the TC Frame Header, N(S). (See Figure 3.1). These variables are defined in Section 3.2.

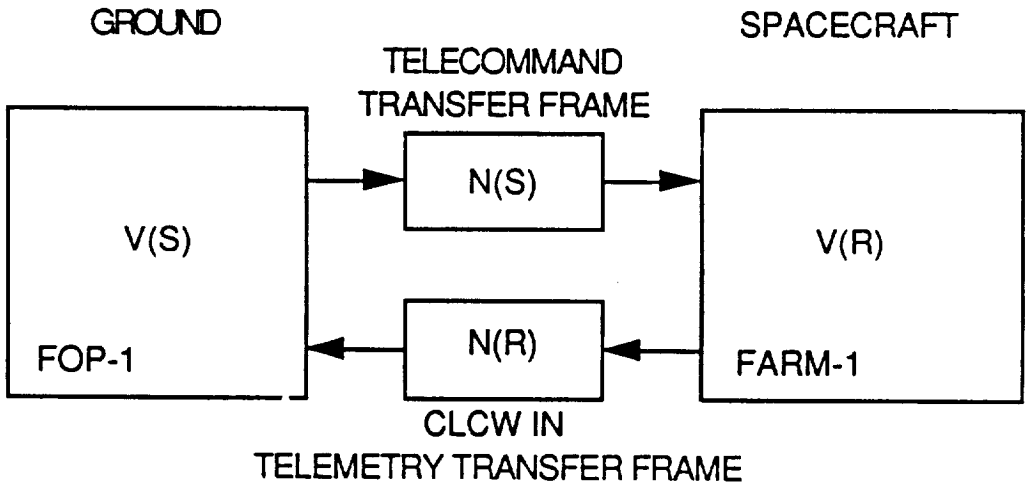


Figure 3.1 COP-1 Variables and Report Values

The AD Service also offers, if required, a flow control mechanism ("Wait" system) which permits the higher layers onboard the spacecraft to signal that they are not able to cope with the incoming rate of uplink telecommand data.

For the BC Frames, the automatic retransmission procedure makes use of a very small number of variables, the most notable being the "Lockout" flag in the CLCW for the "Unlock" control frame, and the value "N(R)" in the CLCW for the "Set V(R)" control frame.

(b) Expedited Service

This service concerns the BD type of frames. BD frames are normally used only in exceptional operational circumstances, typically during spacecraft recovery operations.

The service operates with one directive from the Higher Layer for each TC FDU ("Receive User Data Request from Higher Layer: BD Service" in the FOP-1 State Table). There is only one transmission for each BD frame (i.e., no retransmission). At the sending end, BD frames are given immediate access, as specified by the FOP-1 State Table. At the receiving end, the TC FDU carried by a BD frame will be passed to the Higher Layer immediately, independent of the value of the Lockout or Wait Flags.

Note: Some implementations of FARM-1 may use the same output buffer for FDUs carried by either AD or BD frames in order to provide increased reliability through reduced complexity and lower resource consumption. In this case, when a BD frame is received, an FDU in the process of being transferred or "waiting" to be transferred will be erased, without any indication to the ground in the CLCW. An operational consequence is that for this implementation the sending end Higher Layer shall mandatorily and automatically terminate any ongoing AD Service before starting a BD Service on the same Virtual Channel.

3.1.2 PROTOCOLS

Each end of COP-1 is defined as a protocol machine which is described in a State Table. The description of the format used for the state tables in this document is given in Section 1.3.

The basic operation principle of the protocol machine is that it remains in a state until an event occurs. When an event occurs, it is analysed until it is fully identified and then the operations specified for the combination of that event and that state are executed. Finally the state variable is updated with the new state value specified for the combination.

(i) At the Sending End: FOP-1

The Frame Operation Procedure (FOP-1) protocol machine is described in Table 3-1.

In the case of the arrival of a CLCW, some operations need to be performed before the FOP-1 protocol for the Virtual Channel is invoked. In particular, not included in the FOP-1 State Table are operations such as checking:

- the "COP in Effect"
- the "Virtual Channel Identifier"

Included in the FOP-1 State Table are the following operations:

- checking the value of the Lockout_Flag
- checking the value of N(R)
- checking the value of the Retransmit_Flag
- checking the value of the Wait_Flag

(ii) At the Receiving End: FARM-1

The Frame Acceptance and Reporting Mechanism (FARM-1) protocol machine is described in Table 3-2).

FARM-1 constantly generates a standard report, the CLCW, which is made available to the spacecraft telemetry system at regular intervals (Event E11 in FARM-1 State Table).

Not included in the FARM-1 State Table are operations concerning the validation of the frame. When a "valid frame arrives", this means that the Frame Validation Check process has placed a "valid" frame in the front end buffer of the FARM-1 protocol machine. This validation includes verifying that a control frame is one of the two COP-1 control frames ("Unlock" and "Set V(R)").

Included in the FARM-1 State Table are the following operations:

- checking the value of the Bypass Flag
- checking the value of the Control Flag
- checking the value of N(S) in AD frames

3.1.3 INTERLAYER INTERFACES

In order to define the COP-1 services and protocols completely and clearly, it was necessary to define some of the characteristics of the interface between the COP and the Higher and Lower Layers. For example, a decision had to be made as to whether the Higher Layer delivers only one frame at a time to FOP-1 or may deliver a group of frames. A strategy for ensuring accountability of sequence-controlled frames all the way from the sending end Higher Layer through the spacecraft and back to the Higher Layer had to be established.

It is realized that there are other ways in which the interfaces could be defined. In particular, if two layers are implemented as part of a single system, their interfaces could be simplified. It is the responsibility of the implementors to ensure that all of the requirements for the basic operation of the COP are met.

Communication interfaces are commonly defined in terms of "service primitives", which may contain parameters. In this Section requests from a sending end higher layer for action by a lower layer are referred to as "Directives". The layer receiving the request returns an Accept or Reject Response, depending on whether or not it will attempt to execute the request. The response does not have to be issued immediately; the layer may wait until it has determined

whether it can attempt execution. For example, FOP-1 does not issue the Accept Response to the Higher Layer for a request to transmit an AD frame until it has actually passed the frame to the Lower Layer. This way the Higher Layer can use the Accept Response from one AD frame to initiate the request to transmit the next frame.

For some directives, it is necessary to know whether the action was successfully completed. In these cases a Confirm Response is used in addition to the Accept Response. A Positive Confirm Response means that the action was successfully completed. A Negative Confirm Response means either that the action was not successfully completed or that it will not be possible to determine whether it was successfully completed. There may be a considerable time period between the Accept Response and the Confirm Response. For example, if the request is to transmit an AD Frame, the Confirm Response will not be issued until receipt of the frame on-board has been acknowledged by a CLCW (Positive Confirm) or it has been established that the sequence-controlled service has failed (Negative Confirm).

The service primitive from a receiving end lower layer to a higher layer denoting that data has been received is called an "Indication". There are no specific responses defined in this Section from the receiving end higher layer to lower layer. An Indication is also used to provide status information from a sending end lower layer to higher layer. For example, an Alert Indication is used to notify the Higher Layer that COP-1 has failed, with a parameter giving the type of failure .

3.2 INTERNAL VARIABLES

This section describes the variables used by the COP-1 protocol machines at each end of the Transfer Layer link. The complete meaning of these variables can only be fully understood in conjunction with a careful reading of the COP-1 State Tables. It is these tables which, ultimately, contain the master definition of the COP-1 protocol.

These variables are those which are defined as part of the protocol. Any implementation of the protocol machines is likely to have in addition many private, implementation-dependent variables.

3.2.1 FOP-1 VARIABLES

For each Virtual Channel the sending end protocol machine maintains the following variables:

- State
- Stored_Lockout_Flag
- Stored_Wait_Flag
- Stored_Retransmit_Flag
- Transmitter_Frame_Sequence_Number (usually referred to as V(S)).
- Wait_Queue
- Sent_Queue
- To_Be_Retransmitted_Flag
- AD_Out_Flag
- BD_Out_Flag

- BC_Out_Flag
- Expected_Acknowledgement_Frame_Sequence_Number (usually referred to as NN(R))
- Timer_Initial_Value (also known as T1_Initial)
- Transmission_Limit
- Transmission_Count
- FOP_Sliding_Window_Width (also known as K).
- Timeout_Type (TT)
- Suspend_State (SS)

These are described in detail in the following sections.

(i) State

The state of FOP-1 may be one of:

- Active (S1)
- Retransmit without Wait (S2)
- Retransmit with Wait (S3)
- Initialising without BC Frame (S4)
- Initialising with BC Frame (S5)
- Initial (S6)

This variable represents the state of FOP-1 for the specific Virtual Channel. Each value of the State variable corresponds to a column in the FOP-1 State Table, Table 3.1.

"Active" state (S1) is the normal state of the protocol machine when there are no recent errors on the link and no incidents have occurred leading to flow control problems.

The protocol machine is in the "Retransmit without Wait" state (S2) while the Retransmit_Flag is "on" in the CLCW of the Virtual Channel but no other exceptional circumstances prevail.

The protocol machine is in the "Retransmit with Wait" state (S3) while the Wait_Flag is "on" in the CLCW of the Virtual Channel (Some frames must always be retransmitted when the Wait_Flag is reset, since the Wait_Flag is set only when at least one frame has been discarded.).

The protocol machine is in the "Initialising without BC Frame" state (S4) after receiving an "Initiate AD Service (with CLCW check) Directive" while in the "Initial" state. A successful CLCW check will result in a transition to S1.

The protocol machine is in the "Initialising with BC Frame" state (S5) after receiving an "Initiate AD Service (with Unlock) Directive" or "Initiate AD Service (with Set V(R)) Directive" while in the "Initial" state with BC_Out = Ready. A successful transmission of the BC frame and a subsequent "clean" CLCW status will result in a transition to S1.

The protocol machine is in the "Initial" state (S6) whenever it is necessary to terminate an on-going service (this happens when a "Terminate AD Service Directive" is received or when an "Exception", i.e. an event which causes an Alert, occurs). In principle, the "Initial" state is the first state entered by the protocol machine for a particular Virtual Channel. Although, in principle, all these Virtual Channels remain open during the life of the spacecraft, provision has to be made for interruptions of the physical link between the ground and the spacecraft and the operation of the one physical link from different ground stations. These considerations mean that it must be possible to start up a protocol machine on the ground more than once during the life of the spacecraft.

In the Initial State TC FDUs may only be transmitted if they are BD frames. To start the sequence-controlled service, it is necessary to execute one of the four possible "Initiate AD Service Directives". If the directive is accepted and successfully executed, the protocol machine will be set to the "Active" state (S1). If the directive is not successfully executed (as would be the case if the transmission of an Unlock BC frame is not confirmed in the CLCW reports from the spacecraft after the maximum allowed number of timer-initiated retransmissions), FOP-1 generates an Alert Indication and re-enters the "Initial" state.

(ii) Stored_Lockout_Flag

The Stored_Lockout_Flag contains the value of the Lockout_Flag from the previous CLCW on that Virtual Channel.

(iii) Stored_Wait_Flag

The Stored_Wait_Flag contains the value of the Wait_Flag from the previous CLCW on that Virtual Channel.

(iv) Stored_Retransmit_Flag

The Stored_Retransmit_Flag contains the value of the Retransmit_Flag from the previous CLCW on that Virtual Channel.

(v) Transmitter_Frame_Sequence_Number, V(S)

The Transmitter_Frame_Sequence_Number, V(S), contains the value of the Frame_Sequence _Number, N(S), to be put in the Transfer Frame Header of the next type AD frame to be transmitted.

(vi) Wait_Queue

When Type AD TC FDUs are received from the Higher Layer they are held in the Wait_Queue until they can be accepted by the Transfer Layer. The Wait_Queue has a maximum capacity of one TC FDU.

The Wait_Queue and Accept response to Request to Transfer FDU form the primary mechanism by which flow control as seen by the higher Layer is governed. When an FDU is on the Wait_Queue, this means that the Higher Layer has not yet received an Accept response for the corresponding Request to Transfer FDU.

(vii) To_Be_Retransmitted_Flag

If retransmissions of the Sent_Queue are to be done because one or more frames were not acknowledged within the time allowed or were negatively acknowledged by a CLCW with the Retransmit Flag set , it is not reasonable to shut out all other FOP activity until the last frame on the Sent_Queue has been accepted by the Lower Layer (especially since the Lower Layer uses the Accept response as its flow control mechanism). During that possibly extended time other events may occur, such as the arrival of a CLCW, which must be processed. To handle this situation, each frame on the Sent_Queue carries a To_Be_Retransmitted Flag to distinguish a frame that has been transmitted (or retransmitted) and is awaiting acknowledgement (Flag reset) from one that must be retransmitted (Flag set). Upon receipt of an Accept response from the Lower Layer, these flags will be used to determine which frame on the Sent_Queue, if any, to retransmit next.

(viii) AD_Out_, BC_Out_ and BD_Out_Flags

FOP-1 records whether or not a Transmit Request for Frame is outstanding for each of the three types of frames: AD, BC and BD. There are therefore three variables:

-AD_Out_Flag (for AD frames)
-BC_Out_Flag (for BC frames)
-BD_Out_Flag (for BD frames).

These may take one of two values:

-Ready
-Not_Ready

When FOP-1 issues a Transmit Request for Frame, it sets the appropriate "Out" variable to Not_Ready. When the Transmit Request is accepted by the Lower Layer, FOP-1 sets the variable to Ready.

(ix) Sent_Queue

The Sent-Queue is a virtual channel data structure in which the master copy of all type AD and BC frames on a Virtual Channel is held between the time a copy of the frame is first passed to the Lower Layers for transmission and the time the Transfer Layer has finished processing the frame.

The Transfer layer has finished processing a type AD or BC frame when:

-it receives (via the CLCW) a positive acknowledgement of receipt of the frame (perhaps after retransmission)

-an event causes the Transfer layer to purge the Sent_Queue (i.e. an "Exception" or a "Terminate AD Service Directive").

Once the processing is finished, the master copy of the frame is removed from the queue and discarded and the (successful or not successful) transfer of the FDU is reported to the Higher Layer by means of a Confirm Response (Positive or Negative).

(x) Expected_Acknowledgement_Frame_Sequence_Number (NN(R))

The Expected_Acknowledgement_Frame_Sequence_Number, NN(R), contains the value of N(R) from the previous CLCW on that Virtual Channel. NN(R)-1 is the value of the sequence number of the latest type AD frame which FOP-1 can guarantee has arrived safely. Because of the loop delay in the communications link, this value may lag behind the value of the onboard Receiver_Frame_Sequence_Number, V(R).

(xi) Timer_Initial_Value (T1_Initial)

Whenever a type AD or BC frame is transmitted, the Timer is started or restarted.

If a frame is lost on the physical link, no positive acknowledgement for that frame will be seen in the CLCW. If no later type AD or BC frame were transmitted on that Virtual Channel, there would be no way for FOP-1 to discover that the frame had not arrived. Therefore each Virtual Channel has a Timer which is started whenever a frame is transmitted or retransmitted. If an acknowledgement is seen for the frame, and no subsequent frame has been transmitted, then the timer is cancelled. If the Timer expires and the FOP Transmission_Count has not reached the FOP_Transmission_Limit (see following variables), it causes an event which initiates recovery action in the FOP-1 protocol machine.

The Timer is not used when a type BD frame is transmitted.

The value to which the Timer is set when it is started or restarted is referred to as T1_Initial and may be changed using the Set T1_Initial Directive.

For normal operation, the smallest value of T1_Initial shall be the sum of the following delays for a given Virtual Channel:

- ground processing time of the layers below FOP-1.

- time required to transmit a maximum-length frame (including the bits needed for the CLTU and coding) as a serial bit stream.

- uplink propagation time (one-way light time, including relay satellite path).

- onboard processing time of the layers below FARM-1.

- worst-case time required to sample and encode FARM-1 status data as a CLCW in the telemetry Transfer Frame.

- time required to transmit a telemetry Transfer Frame.

- downlink propagation time (one-way light time, including relay satellite path).

- ground processing time to extract the CLCW from the telemetry Transfer Frame and to deliver it to FOP- 1.

Note: a smaller value of T1_Initial may be useful for deep space commanding with long round-trip light times. It could be used to force retransmission of the entire Sent_Queue a specified number of times prior to receipt of any acknowledgement CLCWs. Assuming Timeout_Type is set to 1 (see below), FOP-1 would be suspended once the maximum number of transmissions were made. Its operation could then be resumed by the Higher Layer to process the acknowledgement CLCWs. In addition, a small value of T1_Initial could be used to allow the Set V(R) command to be sent without having to verify its acceptance via a CLCW before sending the AD frames. In this case the Higher Layer would be alerted once the allowed number of transmissions of the Set V(R) were made and it could then issue an "Initiate AD Service (without CLCW Check)" Directive.

(xii) Transmission Count Variables

When a Type AD or BC frame is lost, the normal recovery procedure is to retransmit it. If however there is a serious problem on the underlying physical link, no amount of retransmissions will permit an acknowledgement for the frame to appear in the CLCW for the Virtual Channel.

If nothing were done, there would be no way for COP-1 to detect the error. Therefore all FDUs containing user data passed from the ground Higher Layer (as well as all directives from the Control Authority in the Higher Layers) have associated with them, at least implicitly, a limit to the number of times the corresponding frame is to be transmitted.

In order to keep from declaring that the link has failed when it is in fact getting frames into the spacecraft, the transmission count limit applies only to the first frame on the Sent_Queue. Once that frame is acknowledged, the count is reset, even though the remaining frames on the Sent_Queue have been transmitted, possibly more than once. The effect is that the transmission count can be considered to be associated with the Sent_Queue, rather than with each frame.

Three FOP-1 variables are used for controlling the retransmissions.

(a) Transmission_Limit

The Transmission_Limit holds a value which represents the maximum number of times the first frame on the Sent_Queue may be transmitted. This includes the first "transmission" and any subsequent "retransmissions" of the frame.

The value of the Transmission_Limit may be changed using the Set Transmission_Limit Directive.

(b) Timeout_Type (TT)

The Timeout_Type variable is referred to as TT. It may take one of two values, 0 or 1. It specifies the action to be performed when both the Timer expires and the FOP Transmission_Count (see next variable) has reached the FOP Transmission_Limit.

(c) Transmission_Count

There are two different sorts of events which may cause FOP-1 to initiate retransmission of either a BC frame or one or more AD frames:

* A CLCW arrives which negatively acknowledges a frame (Retransmit_Flag = 1).

* The Timer expires before a CLCW positively acknowledging the last frame on the Sent_Queue has been received.

Whenever a CLCW arrives which negatively acknowledges a frame, FOP-1 checks whether the value of the Transmission_Count has reached the value of the Transmission_Limit. If it has not, FOP-1 increments the count and initiates retransmission of the frames on the Sent_Queue. If it has, FOP-1 generates an Alert Indication.

Whenever the Timer expires before a CLCW positively acknowledging the last frame on the Sent_Queue has been received, FOP-1 checks whether the value of the Transmission_Count has reached the value of the Transmission_Limit. If it has not, FOP-1 increments the count and initiates retransmission of the frames on the Sent_Queue. If it has, FOP-1 selects one of two types of possible actions depending on the value of the Timeout_Type, TT:

* if TT = 0, FOP-1 generates an Alert Indication.

* if TT = 1, FOP-1 suspends the AD Service, which may be resumed later if so required (see definitions of Suspend_State variable, SS, and Resume AD Service Directive). This feature is used, typically, for deep space commanding.

Whenever one or more frames are acknowledged and therefore removed from the Sent_Queue, the Transmission_Count is reset to 1. The Transmission_Count is also set to 1 when FOP-1

prepares an AD or BC frame for transmission and the Sent_Queue was previously empty. All these actions are defined in detail in Section 3.5, Actions.

For the Expedited Service (BD), there is no Transmission_Count variable, because each BD frame is only transmitted once.

(xiii) Suspend_State (SS)

The Suspend_State variable is referred to as SS. It may take one of five values, from 0 to 4. It records the State that FOP-1 was in when the AD Service was suspended (as described in paragraph (xii) above). This is the State to which FOP-1 will return should the AD Service be resumed. If SS=0, the AD Service is deemed not suspended.

(xiv) FOP_Sliding_Window_Width (K)

The value to which the FOP_Sliding_Window_Width is set is referred to as "K" and may be changed using the Set FOP_Sliding_Window_Width Directive.

The FOP Sliding Window is a mechanism which limits the number of Transfer Frames which can be transmitted ahead of the last acknowledged frame, i.e. before a telemetered CLCW report is received which updates the status of acknowledged frames. This is to prevent sending a new frame with the same sequence number as a rejected frame.

The value "K" shall be set to a value between the following limits:

$$1 <= K <= PW$$

and

$$K < 256$$

where PW is the FARM_Positive_Window_Width as defined in Section 3.2.2, FARM-1 Variables, paragraph (vii)

3.2.2 FARM-1 VARIABLES

For each Virtual Channel the receiving end protocol machine maintains the following variables:

- State
- Lockout_Flag
- Wait_Flag
- Retransmit_Flag
- Receiver_Frame_Sequence_Number (usually referred to as V(R))
- FARM-B_Counter

- FARM_Sliding_Window_Width (also known as W)
- FARM_Positive_Window_Width (also known as PW)
- FARM_Negative_Window_Width (also known as NW)
- Buffer Administration Variables

Finally each Virtual Channel must have available some storage for use as buffers. This implies the existence of data structures for administering the buffers.

These variables are described in detail in the following sections.

(i) State

The State may be one of:

- Open (S1)
- Wait (S2)
- Lockout (S3)

This variable represents the state of FARM-1. Each value of the State variable corresponds to a column in the FARM-1 State Table, Table 3.2.

In Open State, the protocol machine accepts in-sequence frames and passes them to the Higher Layer.

In Wait State, there is no buffer space available in which to place any further received Type AD user data frames. The protocol machine enters the Wait State when it has received a Type A TC FDU, but is unable to deliver it to the Higher Layer. It leaves the Wait State upon receipt of a buffer release signal from the Higher Layer.

Lockout State is entered if the protocol machine receives a frame with sequence number N(S) outside the range expected if FOP-1 is operating correctly. It is a safe state in that no user data will be accepted or transferred to the Higher Layer when in the Lockout State (unless bypass is used). The protocol machine leaves the Lockout State upon receipt of an Unlock control command.

(ii) Lockout_Flag

The Lockout_Flag is set to "1" whenever the protocol machine is in Lockout State; otherwise, it is "0". When the CLCW is to be encoded for a particular Virtual Channel, the value of this flag is read out into the CLCW of that Virtual Channel.

(iii) Wait_Flag

The Wait Flag is set to "1" whenever the protocol machine is in Wait State; otherwise, it is "0". When the CLCW is to be encoded for a particular Virtual Channel, the value of this flag is read out into the CLCW of that Virtual Channel.

(iv) Retransmit_Flag

The Retransmit_Flag is set to "1" whenever the protocol machine knows that a type AD frame has been lost in transmission or has been discarded because there was no buffer space available; otherwise, it is "0". When the CLCW is to be encoded for a particular Virtual Channel, the value of this flag is read out into the CLCW of that Virtual Channel. The appearance of the set condition of the flag on the ground forms a negative acknowledgement of all previously transmitted frames with a N(S) equal to or greater than N(R). The Flag will be reset to "0" upon successful receipt of a frame with N(S) = N(R), receipt of a Set V(R) control command (unless in Lockout State) or receipt of an Unlock control command.

(v) FARM-B_Counter

This variable is incremented whenever a valid BD or BC frame arrives. The value of this variable is read out into the CLCW but is not used by the COP-1 protocol machines at either end of the link. The counter is intended for use by layers above the Transfer Layer to offer a minimal facility for a Higher Layer error control loop when using bypass mode.

How the Higher Layers access the CLCW to obtain the value of the FARM-B_Counter is not defined in this specification. It is implementation dependent.

(vi) Receiver_Frame_Sequence_Number V(R)

This variable records the value of the N(S) expected to be seen in the next type AD frame on this Virtual Channel.

(vii) FARM Sliding Window Variables

The purpose of the COP-1 Sliding Windows is to protect FARM-1 against the unauthorized (uncontrolled) transfer of a sequence of frames such that the Frame Sequence Number, N(S), of one or more of these frames will exceed the current value of the Receiver_Frame_Sequence_Number, V(R), by at least 256.

The purpose of the FOP Sliding Window (defined in terms of its width "K" in Section 3.2.1, FOP-1 Variables, Paragraph (xiv) is to limit the number of frames which can be transmitted safely ahead of the last acknowledged frame. The purpose of the FARM Sliding Window is to protect FARM-1 against any malfunction or erroneous set-up of FOP-1.

The FARM Sliding Window is defined in terms of three variables:

*its total width, referred to as "W"
*the width of its positive part, referred to as "PW"
*the width of its negative part, referred to as "NW"

The three variables are specified in the next subparagraphs, as well as the main related actions. Figure 3.2 illustrates the FARM Sliding Window concept with its different sections and actions.

(viii) FARM_Sliding_Window_Width (W)

The FARM_Sliding_Window_Width is referred to as "W" and gives the range over which the Frame Sequence Numbers of received AD frames may vary without lockout occurring.

The value "W" shall be set to a value between the following limits:

$$2 <= W <= 254$$

where W is always an EVEN integer.

Unless otherwise specified, the value "W" shall be fixed for the entire duration of the mission. In particular, there are no COP-1 control commands for changing the value.

(ix) FARM_Positive_Window_Width (PW) and FARM_Negative_Window_Width (NW)

As shown in Figure 3.2:

*The FARM Positive Window area starts with V(R) and extends PW frames in the positive direction.

*The FARM Negative Window area starts at V(R) - 1 (the number of the last accepted frame) and extends NW frames in the negative direction.

The widths of both parts of the FARM Sliding Window are specified as follows:

$$PW = NW = W/2$$

A Frame Sequence Number, N(S), falls outside the FARM Sliding Window (e.g., into the lockout area of width 256 -W) when:

$$N(S) > V(R) + PW - 1$$

and

$$N(S) < V(R) - NW$$

When the frame is in the lockout area, FARM-1 will discard the frame, go into the Lockout State and set the Lockout Flag.

When N(S) falls inside the FARM Sliding Window, one of the following three cases will occur:

*FIRST CASE

$$N(S) = V(R)$$

The frame is in the positive window and contains the expected Frame Sequence Number; the frame is accepted. This is the case when COP-1 is operating correctly and no previous frames have been lost or discarded. It is also the case when retransmitted frames are received after they have been lost or discarded.

*SECOND CASE

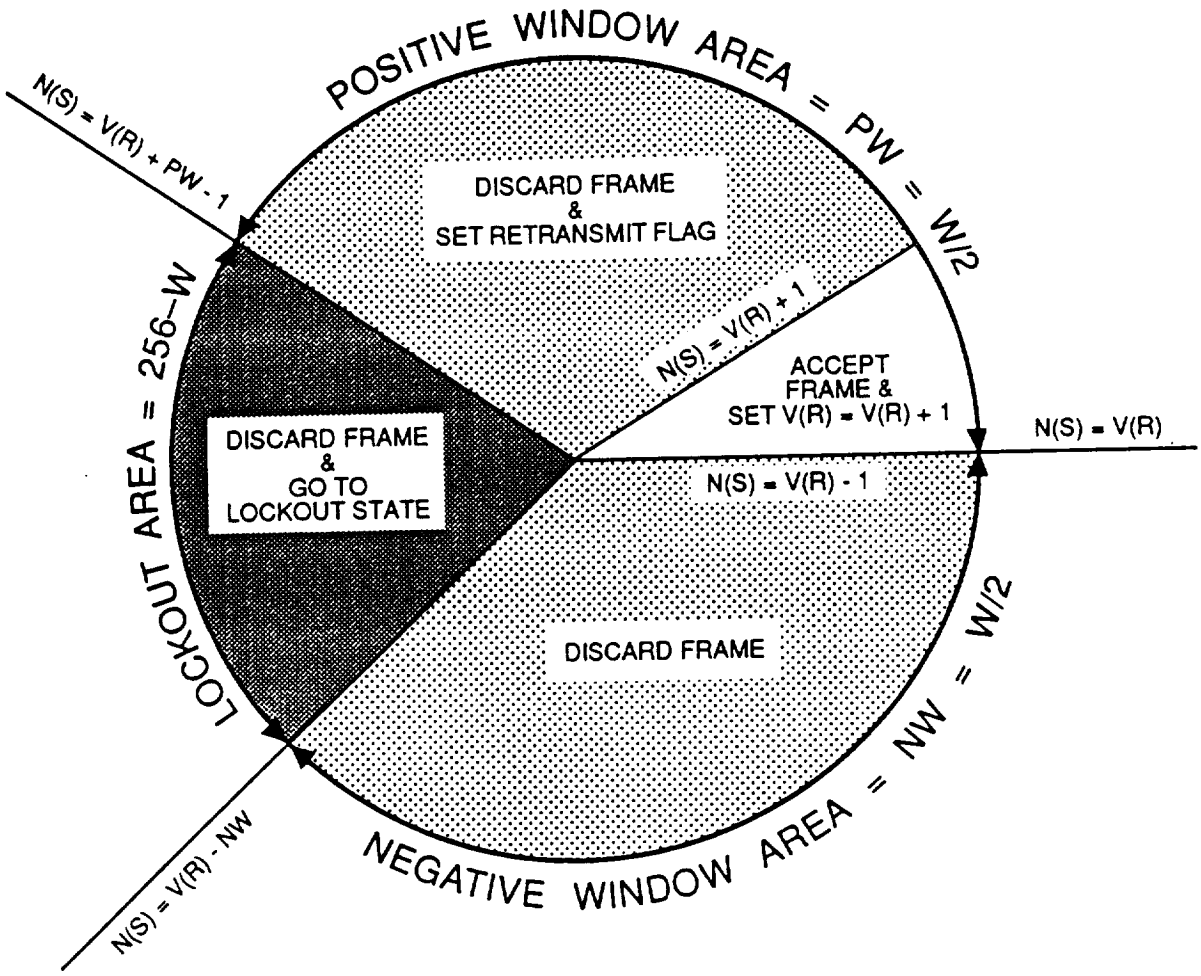
$$N(S) > V(R)$$

and

$$N(S) <= V(R) + PW - 1$$

The frame is in the positive window and does not contain the expected Frame Sequence Number; the frame is discarded and the Retransmit Flag is set, if it has not already been set. This case occurs when a previous frame has been lost or discarded and retransmission has not yet started.

Figure 3.2 FARM Sliding Window Concept



*THIRD CASE

$$N(S) < V(R)$$

and

$$N(S) => V(R) - NW$$

The frame is in the negative window and is discarded without any other action being taken. This case occurs if frames are retransmitted even though they have been accepted. This could happen, for example, if the FOP T1_Initial has been set to a too-small value or if there is a telemetry outage. It may occur during operations using the forced-retransmission mechanism for deep space missions.

NOTE:Certain missions may require only a single transmission of a sequence of AD Frames in one COP-1 session (Transmission_Limit = 1), whether in the Suspend/Resume mode of operation or not. For such missions, and in such a mode it is permitted to set PW > NW, with, ultimately, NW = 0 and PW = W, where W can be any integer between 1 and 256 inclusive. Thus:

$$PW <= W$$

and

$$1 <= W <= 256$$

and

$$1 <= PW <= 256$$

Whatever the value of PW, the value of the FOP_Sliding_Window_Width, K, may never exceed 255.

(x) Buffer Administration Variables

The receiving end of the Transfer Layer requires storage to process the frames arriving from the ground and to contain data to be passed to the Higher Layer.

The actual storage allocation strategy is implementation dependent. However the way FARM-1 is defined in the state tables implies that certain aspects of this strategy are not implementation dependent. These are described here.

The FARM-1 state tables imply the existence of the following FARM-1 buffers:

-one "front end" buffer to contain one maximum length frame for use while the Transfer Layer Frame Validation Checks are performed.

-at least one "back end" buffer to contain the data (TC FDUs) to be passed to the Higher Layer.

If only one "back end" buffer is provided, the main requirement is that the data contained in incoming BD frames have priority : if the back end buffer still contains data, these data shall be erased and the buffer made available to the incoming (BD) FDU. (See Note in Section 3.1.1, Paragraph (b).)

3.3 COP-1 INTERFACE TO HIGHER LAYER

3.3.1 SENDING END

In addition to the normal data transfer interfaces to the FOP-1 protocol machine, a number of management functions may be performed by the Higher Layers. These may be regarded as either a special set of commands from the Higher Layer (with the Higher Layer description modified to include them) or they may be regarded as a separate higher interface to the Transfer Layer. It is also expected that additional status information will be passed from FOP-1 to the Higher Layer for use in performance monitoring and problem diagnosis.

In order to describe the way the Transfer Layer responds to requests from the Higher Layers, we consider the Higher Layer to Transfer Layer interface as two separate interfaces:

- a Sequence-Controlled Service Interface
- an Expedited Service Interface

The Sequence-Controlled Service (short name: AD Service) consists essentially of guaranteeing the successful transfer of TC FDUs by means of AD frames. However, the two BC frames are also generated and serviced when the proper Directive is sent.

The Expedited Service (short name: BD Service) consists essentially of transmitting each TC FDU in one BD frame.

The following service primitives, described in detail in the next subsections, are defined for each Service Interface:

o Sequence-Controlled Service Interface:

- many different Directives
- Accept Response to Directive
- Reject Response to Directive
- Positive Confirm Response to Directive

- Negative Confirm Response to Directive
- Alert Indication
- Request to Transfer FDU
- Accept Response to Request to Transfer FDU
- Reject Response to Request to Transfer FDU
- Positive Confirm Response to Request to Transfer FDU
- Negative Confirm Response to Request to Transfer FDU

o Expedited Service Interface

- Request to Transfer FDU
- Accept Response to Request to Transfer FDU

(a) Sequence-Controlled Service Management Interface

The Sequence-Controlled Service Management Interface is the service access point for exchanging information between the management functions of the Higher Layers and the Transfer Layer.

This access point serves to permit the Higher Layer to request services from the Transfer Layer in connection with managing a Virtual Channel. These service requests are referred to in this document as Directives.

In addition, the access point serves to permit the Transfer Layer to report the status of a Virtual Channel to the Higher Layers. In particular, exception conditions are signalled by means of a service primitive called an Alert Indication.

The service primitives defined on this interface are described hereafter.

NOTE: Other management information, such as spacecraft identification, TC codeblock length, uplink bit rate, etc., which must be provided by the Higher Layers, is not included here for the sake of clarity: their detailed implementation not only reflects the layered nature of the telecommand system, but also the operational philosophy of the network facilities, which is outside the scope of this Recommendation.

1) - Directives

Service Requests from the Higher Layer management function are referred to here as "directives". These are:

- 4 Initiate AD Service Directives

- 1 Terminate AD Service Directive

- 1 Resume AD Service Directive

- 5 FOP-1 Setup Directives

Furthermore, any other Directive will be rejected and reported as

- an "Invalid" Directive

The 12 directives correspond to Events E23 through E40 in the FOP-1 State Table. They are:

- Initiate AD Service (without CLCW check) Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Initiate AD Service (with CLCW check) Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Initiate AD Service (with Unlock) Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Initiate AD Service (with Set V(R)) Directive
  Parameters:
  - V*(R), the new value for V(R)
  - directive identifier
  - Virtual Channel identifier

- Terminate AD Service Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

-Resume AD Service
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Set V(S) to V*(S) Directive
  Parameters:
  - V*(S), the new value for V(S)
  - directive identifier
  - Virtual Channel identifier

- Set FOP_Sliding_Window_Width Directive
  Parameters:
  - new value for width of FOP Sliding Window (K)
  - directive identifier
  - Virtual Channel identifier

- Set T1_Initial Directive
  Parameters:
  - new value for Timer_Initial_Value (T1_Initial)
  - directive identifier
  - Virtual Channel identifier

- Set Transmission_Limit Directive
  Parameters:
  - new value for Transmission_Limit
  - directive identifier
  - Virtual Channel identifier

- Set Timeout_Type Directive
  Parameters:
  - new value for Timeout_Type (TT)
  - directive identifier
  - Virtual Channel identifier

- Invalid Directive
  Parameters:
  - any invalid directive identifier
  - Virtual Channel identifier

2) - Responses

Asynchronously from the directive, the Transfer Layer returns a Response to Directive. This indicates whether FOP-1 will try to execute the directive. This may be one of:

- Accept Response to Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Reject Response to Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

After each Accept Response to Directive, but asynchronously from that Response, the Transfer Layer signals to the Higher Layer a Confirm Response referring to the directive. This indicates whether or not COP-1 (including FARM-1 for directives requiring receiving end action) was able to complete the execution of the directive. This may be one of:

- Positive Confirm Response to Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

- Negative Confirm Response to Directive
  Parameters:
  - directive identifier
  - Virtual Channel identifier

The Negative Confirm Response to Directive service primitive does not carry a parameter giving the reason for the failure to confirm performance of the service requested by the Directive. However, whenever a condition is detected which might give rise to Negative Confirm Response to Directive service primitives, an Alert Indication is signalled from the Transfer Layer to the Higher Layer.

3) - Alert Indications

If an unrecoverable error occurs on the link, then the Transfer Layer passes an indication to the Higher Layer.

- Alert indication
  Parameters:
  - reason for alert
  - Virtual Channel identifier

This alert indication serves as notice of the termination of the Sequence-Controlled Service guarantee.

The reason for an Alert Indication may be one of the following:

- Allowed number of transmissions exhausted for an AD frame: Alert [limit]. (Note: This Alert Indication cannot occur if the timer has expired and the Timeout_Type variable is set to '1').

- Allowed number of transmissions exhausted for a BC frame derived from a directive (e.g. Initiate AD Service Directive with "Unlock" or with "Set V(R)"): Alert [limit].

- Lockout detected: Alert [lockout].

- CLCW with Retransmit Flag = O and N(R) = NN(R) has arrived when last CLCW seen previously showed Retransmit Flag = 1: Alert[synch].

- All frames sent are acknowledged but Retransmit_Flag is "on": Alert[synch].

- An attempt to acknowledge frames is made during the initializing phase corresponding to State (S4): Alert[synch].

- CLCW with invalid N(R) has arrived: Alert[NN(R)].

- CLCW with Wait Flag = 1 and Retransmit Flag = 0 has arrived: Alert[CLCW].

- CLCW with invalid pattern of bits has arrived: Alert[CLCW].

- FOP-1 and Lower Layer are out of synchronisation (Lower Layer rejects frame even though appropriate OUT flag is set to Ready): Alert [LLIF].

- A "Terminate AD Service Directive" has arrived: Alert[term].

The Alert Indication implies the end of the Sequence-Controlled Service guarantee on the error free transfer of data to the spacecraft. Higher Layer recovery actions are necessary to try to ensure that data are not lost, duplicated or erroneous.

The Alert Indications relating to the transmission count may be as a result of a break in the underlying physical link and may therefore be caused by problems outside the Transfer Layer.

All other Alert Indications report the breakdown of the Transfer Layer protocol. This means that some part of the system is not operating to specification (therefore, reports already received by the layers above FOP-1 are likely to have been incorrect).

In particular, an Alert Indication carries the Virtual Channel identifier corresponding to the FOP-1 in which the error condition was detected; but, given that the protocol mechanism has broken down, it is possible that the Virtual Channel identifier is incorrect. A single failure may cause the same or different Alert Indications on more than one Virtual Channel.

A Lockout Detected Alert will not occur if the Lockout was detected and reported by an earlier Alert Indication and it has not changed since that indication.

4) - Suspend Indication

By setting Timeout_Type to "1" and setting a small value of T1_Initial it is possible to cause FOP-1 to transmit a sequence of Type AD frames a specified number of times and then suspend its operation, without clearing its buffers. The Suspend Indication is used to notify the Higher Layer that the transmissions have been completed and that the operation has been suspended. A subsequent Resume directive will then cause FOP-1 to resume operation in the same state it was in when it was suspended.

(b) Sequence-Controlled Service FDU Transfer Interface

Data transferred through this interface enjoy the protection of all the Transfer Layer facilities and are covered by the guarantee to deliver data without error, in order and without omission or duplication to the spacecraft.

Only one operation may be performed by the Higher Layer on the interface. This is to present to the Transfer Layer:

- Request to Transfer FDU (AD Service)
  Parameters:
  - FDU
  - request identifier
  - Virtual Channel identifier.

After each request, perhaps immediately, perhaps after a delay, the Transfer Layer returns to the Higher Layer a Response referring to the Request. This may be one of:

- Accept Response to Request to Transfer FDU (AD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier

- Reject Response to Request to Transfer FDU (AD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier

In response to this request the Transfer Layer signals its acceptance or rejection of the Request. However, if the Transfer Layer is unable to transmit the FDU immediately (for example because the spacecraft has indicated it cannot immediately accept any more data), then the Transfer Layer will delay signalling to the Higher Layer its acceptance of the FDU from the Higher Layer, even though it places the FDU in its Wait_Queue. The Higher Layer may not issue another Request to Transfer FDU until the current one has been accepted or rejected.

Whenever it has transfer capacity after a period when there was no extra capacity available, the FOP-1 protocol machine looks at the AD Service interface to see if an FDU is in the Wait_Queue. If so, the Transfer Layer accepts the FDU, which is then deemed to be under control of the Transfer Layer.

After each Accept Response to Request to Transfer FDU (AD Service), but asynchronously from the Response, the Transfer Layer signals to the Higher Layer a confirm response referring to the Request. This may be one of:

- Positive Confirm Response to Request to Transfer FDU (AD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier

- Negative Confirm Response to Request to Transfer FDU (AD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier

Because there may be a number of FDUs which have been accepted, but not confirmed, the two layers need to share a common system of request identifiers for use when referring to a particular request (and, therefore, to a particular FDU).

The Positive Confirm Response to Request to Transfer FDU (AD Service) notifies the Higher Layer that the FDU was received on board and acknowledged by a CLCW. If the Transfer Layer is unable to guarantee that an FDU was transferred on board despite retry attempts, a Negative Confirm Response for that FDU is passed to the Higher Layer.

The Negative Confirm Response to Request to Transfer FDU (AD Service) does not carry a parameter giving the reason for the failure to confirm the requested data transfer service. However whenever a condition is detected which might give rise to such responses, an Alert Indication is signalled from the Transfer Layer to the Higher Layer.

From the point of view of the Higher Layer, between the time of acceptance of an FDU by the Transfer Layer until a positive confirm response is received, the FDU is in a "Grey Area" in which it is not possible to know if it has been transferred on board. FDUs for which a negative confirm response is received may have been unsuccessfully uplinked or they may not. Therefore a negative confirm response signals a break in the Sequence-Controlled Service guarantee.

If an FDU has not been accepted, it is deemed to be still under the control of the Higher Layer and is not covered by the Sequence-Controlled Service guarantee. Once FOP-1 detects a problem (for example a failure of the automatic error recovery mechanism to ensure transfer on board) leading to a break in the Sequence-Controlled Service guarantee, it rejects the outstanding Request to Transfer FDU. Therefore an FDU which has not been accepted can never be in the "Grey Area".

(c) Expedited Service Interface

The Expedited Service Interface is the service access point used for FDUs to be transmitted via BD frames.

Data transferred through this interface are covered by the Expedited Service guarantee to deliver data without error, in order, without duplication but with possible omissions (The data are not

duplicated because there is no automatic retransmission mechanism; the frame is transmitted only once). If any error recovery is required, it has to be performed by the Higher Layers.

Only one operation is performed by the Higher Layer on this interface. This is to present an FDU to the Transfer Layer:

- Request to Transfer FDU (BD Service)
  Parameters:
  - FDU
  - request identifier
  - Virtual Channel identifier

After each request, perhaps immediately, perhaps after a delay, the Transfer Layer returns to the Higher Layer a Response referring to the Request. This may be one of:

- Accept Response to Request to Transfer FDU (BD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier.

- Reject Response to Request to Transfer FDU (BD Service)
  Parameters:
  - request identifier
  - Virtual Channel identifier.

As long as the sending end Lower Layers are capable of accepting the BD frame, it will be accepted from the Higher Layer and transmitted. If the Lower Layers cannot accept the BD frame, it will be rejected; there is no Wait_Queue for BD frames.

As no error recovery is performed by COP-1 for a BD frame, a copy of the data is not kept by FOP-1 and no confirmation of its acceptance by the receiving end is signalled on this interface.

3.3.2 RECEIVING END

At the receiving end of COP-1 (i.e. FARM-1), the user data are delivered as a buffer containing an accepted TC FDU. No distinction is made between a TC FDU delivered by means of an AD frame and one delivered by a BD frame. However, the management of the FARM-1 back-end buffer is affected as follows:

- BD frames

When a frame of this type is accepted by FARM-1, the TC FDU it contains shall be placed in the BD back-end buffer of FARM-1 even if this buffer still contains data (partially read out or not), in which case these data will be erased, an abort signal sent to the Higher Layer to signal the erasure and the new data signalled as "arrived".

- AD frames

When a frame of this type is accepted by FARM-1, the TC FDU it contains shall be placed in the AD back-end buffer of FARM-1 and a signal sent to the Higher Layer only when the buffer is available (empty). If the buffer still contains data, the newly arrived AD frame shall be discarded.

Therefore FARM-1 must always know when its back end buffers still contain data. (See also the related Note in Section 3.1.1, Paragraph (b).)

All this can be expressed by the following service primitives:

a) From FARM-1 to Higher Layer

- FDU Arrived Indication
  Parameters:
  -TC FDU data
  - Virtual Channel identifier
  - FDU Aborted Indication

The Virtual Channel identifier is normally implicit.

b) From Higher Layer to FARM-1

No specific service primitive is defined. Any required data flow control signalling may be defined, as long as the back pressure is felt by FARM-1, i.e. FARM-1 must always know whether its AD back end buffer is empty or not.

No interface with the Higher Layer exists for control frames (BC); control commands are used only within COP-1.

Finally, data link service anomalies may result in discontinuities in the data transfer service. This may or may not require erasing incomplete data in the Higher Layers. This problem is mentioned in Section 3.5 (Actions; Note of Paragraph 3.5.2).

3.4 COP-1 INTERFACE TO LOWER LAYER

3.4.1 SENDING END

a) From FOP-1 to Frame Generation

-Transmit Request for Frame
  Parameters:
  - Request Identifier

- Frame Data including:
  - Version/format identifier
  - Type identifier (AD, BD or BC)
  - Spacecraft identifier
  - Virtual Channel Identifier
  - Frame Sequence Number, N(S), for AD frames
  - Data (TC FDU or Control Command)

- Abort Request
  Parameters:
  - Virtual Channel Identifier

b) From Frame Generation to FOP-1

Each Transmit Request is acknowledged with one of two possible responses:

- Accept Response
  Parameters:
  - Request Identifier of Transmit Request
  - Virtual Channel Identifier

- Reject Response
  Parameters:
  - Request Identifier of Transmit Request.
  - Virtual Channel Identifier

3.4.2 RECEIVING END

a) From the Frame Validation Check to FARM-1

- Valid Frame Arrived Indication
  Parameters:
  - Frame Type (AD, BD or BC)
  - Virtual Channel Identifier
  - Frame Sequence Number, N(S), for AD frames
  - Data (TC FDU or Control Command)

The Frame Type information is used for demultiplexing the Frame Data of different services (AD, BD, BC). The Virtual Channel identifier is normally implicit, since there is a separate FARM-1 for each Virtual Channel. Note: all of this information could be transferred by providing the entire frame, including the header.

b) From FARM-1 to the Frame Validation Check

- No service primitives are specified.

3.5 ACTIONS

3.5.1 FOP-1

The actions related to the interface between FOP-1 and the Higher Layer have been covered in Section 3.3.

The FOP-1 State Table (See Table 3.1) expresses the operations to be performed for each event/state combination. Description of the State Table format is included in Section 1.3.

Because of space considerations in the table and in order to avoid repetition in the text of this section, certain abbreviations have been used. These are listed below:

-"Purging the Sent_Queue" includes clearing the Sent_Queue by generating a Negative Confirm response for each frame on the queue and deleting the frame. (Note: Purging the Sent_Queue only occurs as part of the termination of an AD Service).

-"Purging the Wait_Queue" includes clearing the Wait_Queue and generating a Reject Response for the queued FDU.

-"Transmit", for an AD or BC Frame (i.e. for the Sequence-Controlled Service), includes all the functions necessary to prepare a frame for transmission. In particular it includes:

- inserting the current value of V(S) into the N(S) field of the frame and then incrementing V(S) (for AD frames only)

- adding the master copy of the frame to the Sent_Queue (for AD and BC frames) with the To_Be_Retransmitted_Flag NOT set

-if the Sent_Queue was previously empty, setting the Transmission_Count to 1 (for AD and BC frames).

- starting the Timer (for AD and BC frames)

- setting the AD_Out (or BC_Out) Flag to Not_Ready

- passing a copy of the frame (AD or BC) to the Lower Layer as a parameter of a Transmit Request for (AD or BC) Frame

-"Transmit", for a BD Frame (i.e. for the Expedited Service), includes all the functions necessary to prepare the frame for transmission. In particular it includes:

-setting the BD_Out Flag to Not_Ready

- passing a copy of the BD frame to the Lower layer as a parameter of a Transmit Request for (BD) Frame

- "Initiate AD (or BC) Retransmission" includes:

- passing an Abort Request to the Lower Layer

- incrementing the Transmission Count

- starting the Timer

- marking all AD frames (or the BC frame) on the Sent_Queue as "To_Be_Retransmitted"

- "Remove Acknowledged Frames from Sent_Queue" includes:

- generating a Positive Confirm Response to Request to Transfer FDU for each acknowledged frame and deleting the frame

- updating the value of NN(R)

- setting the Transmission_Count to 1

- "Alert" includes:

- cancelling the Timer

- purging the Sent_Queue

- purging the Wait_Queue

-completing the processing of any Initiate AD Service Directive by generating a Negative Confirm response for the Directive

-generating an Alert signal to the Higher Layer

- "Look for Directive" includes:

-checking if the BC_Out_Flag is set to Ready. If not, no further processing can be performed for retransmitting the BC frame until an Accept Response is received for the outstanding Transmit Request for (BC) Frame, setting the BC_Out_Flag to Ready.

-if the BC_Out_Flag is set to Ready, checking if the BC frame on the Sent_Queue is flagged "To_Be_Retransmitted". If so, the flag is set to Not_Ready and a copy of the BC frame is passed to the Lower Layer as a parameter of a Transmit Request for (BC) Frame.

- "Look for FDU" includes:

-checking if the AD_Out_Flag is set to Ready. If not, no further processing can be performed for transmitting AD frames. (When an Accept Response is received for the outstanding Transmit Request for (AD) Frame, FOP-1 will set the AD_Out_Flag to Ready and execute a new "Look for FDU".)

-if the AD_Out_Flag is set to Ready, checking if an AD frame on the Sent_Queue is flagged "To_Be_Retransmitted". If so, the flag is set to Not_Ready and a copy of the first such AD frame is passed to the Lower Layer as a parameter of a Transmit Request for (AD) Frame and its To_Be_Retransmitted Flag is reset.

-if no AD frame is marked "To_Be_Retransmitted", checking if both V(S)<NN(R)+K and an FDU is available at the AD Service Interface on the Wait_Queue. If so, the FDU is removed from the Wait_Queue, an Accept Response to Request to Transfer FDU is passed to the Higher Layer and the "Transmit" action for AD Frame (see above) is performed.

-if no FDU is available on the Wait_Queue, no further processing is performed.

- "Initialise" includes:

- purging the Sent_Queue

- purging the Wait_Queue

- setting Suspend State (SS) to 0

"Suspend" includes:

- generating a Suspend signal to the Higher Layer

-"Resume" includes:

- starting Timer

- setting Suspend State (SS) to 0

The State Tables show the new state value at the bottom of each box (for example "(S1)").

References to:

- Lockout_Flag
- Wait_Flag
- Retransmit_Flag
- N(R)

pertain to the values in the current CLCW.

The FOP-1 table is large and the state transitions complex. Therefore the newcomer may find it helpful to consider initially only the state changes relating to the main protocol. This is shown, for the normal situation in which no exception conditions occur, in Figure 3.3. This protocol is capable of handling automatically flow control and error control (providing the quality of the link is not so low that a maximum of Transmission_Limit transmissions fail to transfer a frame on board). It is not capable of handling improper operation of the spacecraft link, for example caused by two ground stations simultaneously sending Transfer Frames to the same spacecraft.

Next consideration should be given to the initialisation protocol used, for example, to initiate and terminate a session using the AD Service. This is shown in Figure 3.4 and shows the main protocol States (S1), (S2) and (S3) coalesced into a single state. The FOP-1 State Table distinguishes among many events all of which should never occur. If one of these situations is detected, an Alert signal is passed to the Higher Layer and FOP-1 enters the Initial State (S6). Except for Alert [term] after a "Terminate AD Service Directive', all these traps are grouped under "Exceptions" in Figure 3.4.

A detailed summary of the way FOP-1 moves between all states is given in Figure 3.5.

3.5.2 FARM-1

The actions related to the interface between FARM-1 and the Higher Layer have been covered in Section 3.3.

Various abbreviations are used in the FARM-1 State Table (see Table 3.2). These are listed below:

-"Valid frame arrives" means that the Frame Validation Check has placed a "valid" frame in the front end buffer.

-"Accept" for an AD frame may be subject to a buffer release signal from the Higher Layers if the Higher Layer is implemented to take advantage of the "Wait" concept. When no AD back end buffer is available (Event E2), the frame must be discarded.

-"Accept" for a BD frame means that the data contents of the frame (TC FDU) are placed in the back end buffer even when this buffer still contains data, in which case these previous data are erased. The "Wait" concept does not apply to BD frames: the FDU is deemed to have

unimpaired access to the Higher Layers and the necessary interfaces must be implemented to this effect (recovery requirements specific to the mission).

A summary of the way FARM-1 moves between states is given in Figure 3.6.

In Table 3.2, events E7 and E8 are concerned with the execution of, respectively, an "Unlock" Control Command and a "Set V(R)" Control Command. The specification of each action in each box is self-explanatory. The action described for event E8 in state (S3) means that the Control Command "Set V(R)" is not executed (FARM-1 must be "unlocked" first), but accounted for by means of the FARM-B Counter since it was validated as "legal" and found "executable".

NOTE:The execution of an "UNLOCK" Control Command resets only FARM-1, not the higher layers. Some mechanism should be provided to ensure that the data management functions of the Higher Layers purge/reset their buffers as required for spacecraft operations.

Table 3.1 FOP-1 State Table (Part 1)

		ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
State Name		ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
Main Feature of State		Last CLCW showed: Lockout Flag=0, Retransmit_ Flag=0, Wait_ Flag=0	Last CLCW showed: Lockout Flag=0, Retransmit_ Flag=1, Wait_ Flag=0	Last CLCW showed: Lockout_ Flag=0, Retransmit_ Flag=1, Wait_ Flag=1	Initiate AD Service (with CLCW check) Directive received and "clean" status not seen since	Type BC frame transmitted and "clean" status not seen since	Not Configured for AD Service
State Number		S1	S2	S3	S4	S5	S6
Event Conditions	**Event Number**						
CLCW arrives formed from a valid COP-1 pattern of bits; Lockout_ Flag=0; N(R)= V(S) is: Valid N(R) and all outstanding type AD frames acknow-ledged; Retransmit_ Flag=0; Wait_ Flag=0; N(R)= NN(R) is no new frames acknow-ledged	E1	Ignore (S1)	Alert [synch] (S6)	Alert [synch] (S6)	Confirm, Cancel Timer (S1)	Confirm, Release copy of type BC frame, Cancel Timer (S1)	Ignore (S6)
N(R) <> NN(R) is some new frames acknow-ledged	E2	Remove acknow-ledged frames from Sent_Queue, Cancel Timer, Look for FDU (S1)	Remove acknow-ledged frames from Sent_Queue, Cancel Timer, Look for FDU (S1)	Remove acknow-ledged frames from Sent_Queue, Cancel Timer, Look for FDU (S1)	Not Applicable	Not Applicable	Ignore (S6)
Wait_ Flag=1	E3	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Ignore (S6)
Retransmit_ Flag=1	E4	Alert [synch] (S6)	Alert [synch] (S6)	Alert [synch] (S6)	Alert [synch] (S6)	Ignore (S5)	Ignore (S6)

Table 3.1 FOP-1 State Table (Part 2)

State Name	ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
State Number	S1	S2	S3	S4	S5	S6
Command: CLCW arrives formed from a valid COP-1 pattern of bits	Ignore	Alert [synch]	Alert [synch]	Not applicable	Not applicable	Ignore
Command: Lockout_ Flag=0						
N(R)≤V(S) and N(R)≥ NN(R) is: Valid N(R) and some outstanding type AD frames not yet acknowledged						
Retransmit_ Flag=0						
Wait_ Flag=0	N(R)= NN(R) is no new frames acknowledged	E5	Remove acknowledged frames from Sent_Queue, Look for FDU (S1)	Remove acknowledged frames from Sent_Queue, Look for FDU (S1)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Ignore (S6)
	N(R) ◇ NN(R) is some new frames acknowledged	E6	Remove acknowledged frames from Sent_Queue, Look for FDU (S1)	Remove acknowledged frames from Sent_Queue, Initiate AD Retransmission, Look for FDU (S2)	Alert [synch] (S6)	Alert [synch] (S6)	Ignore (S5)	Ignore (S6)
Wait_ Flag=1		E7	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Alert [CLCW] (S6)	Ignore (S6)
Retransmit_ Flag=1	N(R)>NN(R) is some new frames acknowledged	E8	Remove acknowledged frames from Sent_Queue, Initiate AD Retransmission, Look for FDU (S2)	Remove acknowledged frames from Sent_Queue, Initiate AD Retransmission, Look for FDU (S2)	Remove acknowledged frames from Sent_Queue (S3)	Alert [synch] (S6)	Ignore (S5)	Ignore (S6)
	Wait_ Flag=1	E9	Remove acknowledged frames from Sent_Queue (S3)	Remove acknowledged frames from Sent_Queue (S3)	Remove acknowledged frames from Sent_Queue (S3)	Alert [synch] (S6)	Ignore (S5)	Ignore (S6)

Table 3.1 FOP-1 State Table (Part 3)

State Name	ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL- ISING WITHOUT BC FRAME	INITIAL- ISING WITH BC FRAME	INITIAL
State Number	S1	S2	S3	S4	S5	S6
Commanded CLCW arrives with pattern of bits invalid under COP-1	Commanded: Lockout_ Flag=0	E10	Wait_ Flag=0	Initiate AD Retransmission, Look for FDU	Ignore	Initiate AD Retransmission, Look for FDU	Not applicable	Not applicable	Ignore
		E11	Wait_ Flag=1	Ignore	Ignore	Ignore	Not applicable	Not applicable	Ignore
		E12	Transmission_ Count >= Transmission_ Limit	Alert [limit]	Alert [limit]	Alert [limit]	Not applicable	Not applicable	Ignore
	Commanded: N(R)< V(S) and N(R)>= NN(R) and Invalid N(R)	E13		Alert [NN(R)]	Alert [NN(R)]	Alert [NN(R)]	Alert [NN(R)]	Ignore	Ignore
	Commanded: Retransmit_ Flag=1 and N(R)<NN(R) or N(R)>V(S)	E14		Alert [Lockout]	Alert [Lockout]	Alert [Lockout]	Alert [Lockout]	Ignore	Ignore
	Commanded: Lockout_ Flag=1	E15		Alert [CLCW]	Alert [CLCW]	Alert [CLCW]	Alert [CLCW]	Alert [CLCW]	Ignore
Timer Expires	FOP_ Transmission_ Count < Transmission_ Limit	E16		Initiate AD Retransmission, Look for FDU	Ignore	Alert [limit]	Initiate BC Retransmission, Look for Directive	Not applicable	
	FOP_ Transmission_ Count >= Trans- mission Limit	E17	TT=0	Alert [limit]	Alert [limit]	Alert [limit]	Alert [limit]	Alert [limit]	Not applicable
		E18	TT=1	SS:=1 Suspend	SS:=2 Suspend	SS:=3 Suspend	SS:=4 Suspend	Alert [limit]	Not applicable

Table 3.1 FOP-1 State Table (Part 4)

State Name			ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL- ISING WITHOUT BC FRAME	INITIAL- ISING WITH BC FRAME	INITIAL
State Number			S1	S2	S3	S4	S5	S6
Receive User Data Request from Higher Layer	AD Service	Wait_Queue Empty	E19	Add to Wait_Queue Look for FDU (S1)	Add to Wait_Queue (S3)	Reject (S4)	Reject (S5)	Reject (S6)
		Wait_Queue Not Empty	E20	Reject (S1)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)
	BD Service	BD_Out = Ready	E21	Accept, BD_Out = Not_Ready, Transmit User Data type BD frame (S1)	Accept, BD_Out = Not_Ready, Transmit User Data type BD frame (S3)	Accept, BD_Out = Not_Ready, Transmit User Data type BD frame (S4)	Accept, BD_Out = Not_Ready, Transmit User Data type BD frame (S5)	Accept, BD_Out = Not_Ready, Transmit User Data type BD frame (S6)
		BD_Out = Not_Ready	E22	Reject (S1)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)
Receive Directive from Management Function	Initiate AD Service (without CLCW check)		E23	Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Initialise, Confirm (S1)
	Initiate AD Service (with CLCW Check)		E24	Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Initialise, Start Timer (S4)
	Initiate AD Service (with Unlock)	BC_Out = Ready	E25	Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Initialise, BC_Out = Not_Ready, Transmit Unlock type BC Frame (S5)
	Directive								
		BC_Out = Not_Ready	E26	Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)

Table 3.1 FOP-1 State Table (Part 5)

State Name		ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
State Number		S1	S2	S3	S4	S5	S6
Command Received from Management Function: Initiate AD Service (with Set V(R)) Directive	BC_Out = Ready	E27 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Initialize, V(S) := V*(R), NN(R) := V*(R), BC_Out = Not_Ready, Transmit Set V(R) type BC Frame (S5)
	BC_Out = Not_Ready	E28 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)
Terminate AD Service Directive		E29 Accept, Alert [term], Confirm (S6)	Accept, Alert [term], Confirm (S6)	Accept, Alert [term], Confirm (S6)	Accept, Alert [term], Confirm (S6)	Accept, Alert [term], Confirm (S6)	Accept, Confirm (S6)
Resume AD Service Directive	SS=0	E30 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)
	SS=1	E31 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Resume, Confirm (S1)
	SS=2	E32 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Resume, Confirm (S2)
	SS=3	E33 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Resume, Confirm (S3)
	SS=4	E34 Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, Resume, Confirm (S4)

Table 3.1 FOP-1 State Table (Part 6)

State Name		ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
State Number		S1	S2	S3	S4	S5	S6
Command/ Receive Directive from Management Function	Set V(S) to V*(S) Directive	E35					
		Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Accept, V(S) := V*(S), NN(R) := V*(S), Confirm (S6)
	Set FOP_Sliding Window_Width Directive	E36	Accept, Set K, Confirm (S1)	Accept, Set K, Confirm (S2)	Accept, Set K, Confirm (S3)	Accept, Set K, Confirm (S4)	Accept, Set K, Confirm (S5)	Accept, Set K, Confirm (S6)
	Set T1_Initial Directive	E37	Accept, Set T1_Initial, Confirm (S1)	Accept, Set T1_Initial, Confirm (S2)	Accept, Set T1_Initial, Confirm (S3)	Accept, Set T1_Initial, Confirm (S4)	Accept, Set T1_Initial, Confirm (S5)	Accept, Set T1_Initial, Confirm (S6)
	Set Transmission_Limit Directive	E38	Accept, Set Transmission_Limit, Confirm (S1)	Accept, Set Transmission_Limit, Confirm (S2)	Accept, Set Transmission_Limit, Confirm (S3)	Accept, Set Transmission_Limit, Confirm (S4)	Accept, Set Transmission_Limit, Confirm (S5)	Accept, Set Transmission_Limit, Confirm (S6)
	Set Timeout_Type Directive	E39	Accept, Set TT, Confirm (S1)	Accept, Set TT, Confirm (S2)	Accept, Set TT, Confirm (S3)	Accept, Set TT, Confirm (S4)	Accept, Set TT, Confirm (S5)	Accept, Set TT, Confirm (S6)
	Invalid Directive	E40	Reject (S1)	Reject (S2)	Reject (S3)	Reject (S4)	Reject (S5)	Reject (S6)

Table 3.1 FOP-1 State Table (Part 7)

State Name		ACTIVE	RETRANSMIT WITHOUT WAIT	RETRANSMIT WITH WAIT	INITIAL-ISING WITHOUT BC FRAME	INITIAL-ISING WITH BC FRAME	INITIAL
State Number		S1	S2	S3	S4	S5	S6
Receive Response from Lower Layer	AD_Accept	E41	AD_Out = Ready, Look for FDU ($1)	AD_Out = Ready, Look for FDU ($2)	AD_Out = Ready ($3)	AD_Out = Ready ($4)	AD_Out = Ready ($5)	AD_Out = Ready ($6)
	AD_Reject	E42	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)
	BC_Accept	E43	BC_Out = Ready ($1)	BC_Out = Ready ($2)	BC_Out = Ready ($3)	BC_Out = Ready ($4)	BC_Out = Ready, Look for Directive ($5)	BC_Out = Ready ($6)
	BC_Reject	E44	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)
	BD_Accept	E45	BD_Out = Ready, Accept ($1)	BD_Out = Ready, Accept ($2)	BD_Out = Ready, Accept ($3)	BD_Out = Ready, Accept ($4)	BD_Out = Ready, Accept ($5)	BD_Out = Ready, Accept ($6)
	BD_Reject	E46	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)	Alert [LLIF] ($6)

Figure 3.3 FOP-1 State Transitions: Main Protocol

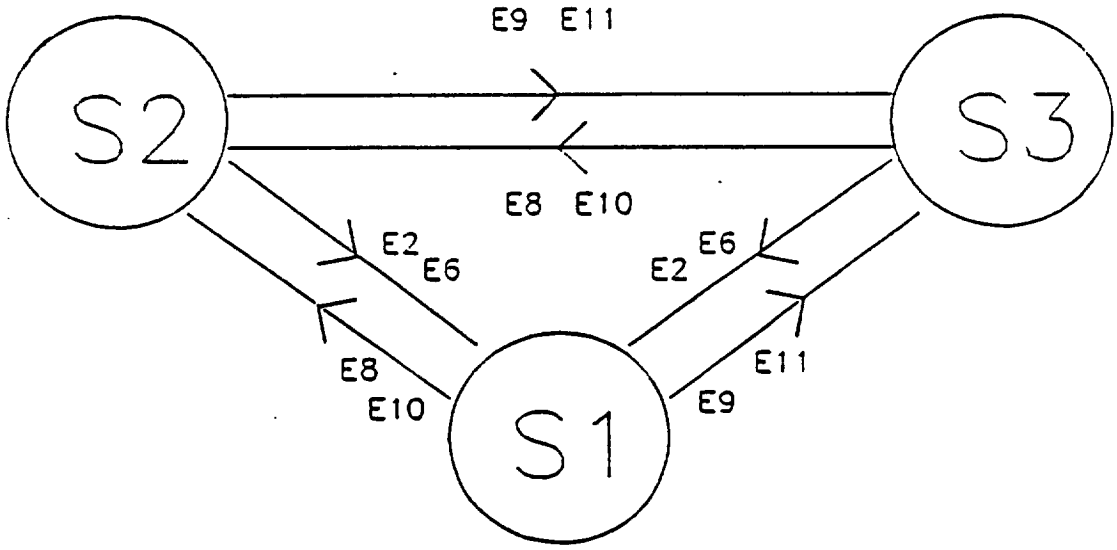


Figure 3.4 FOP-1 State Transitions : Initialisation Protocol

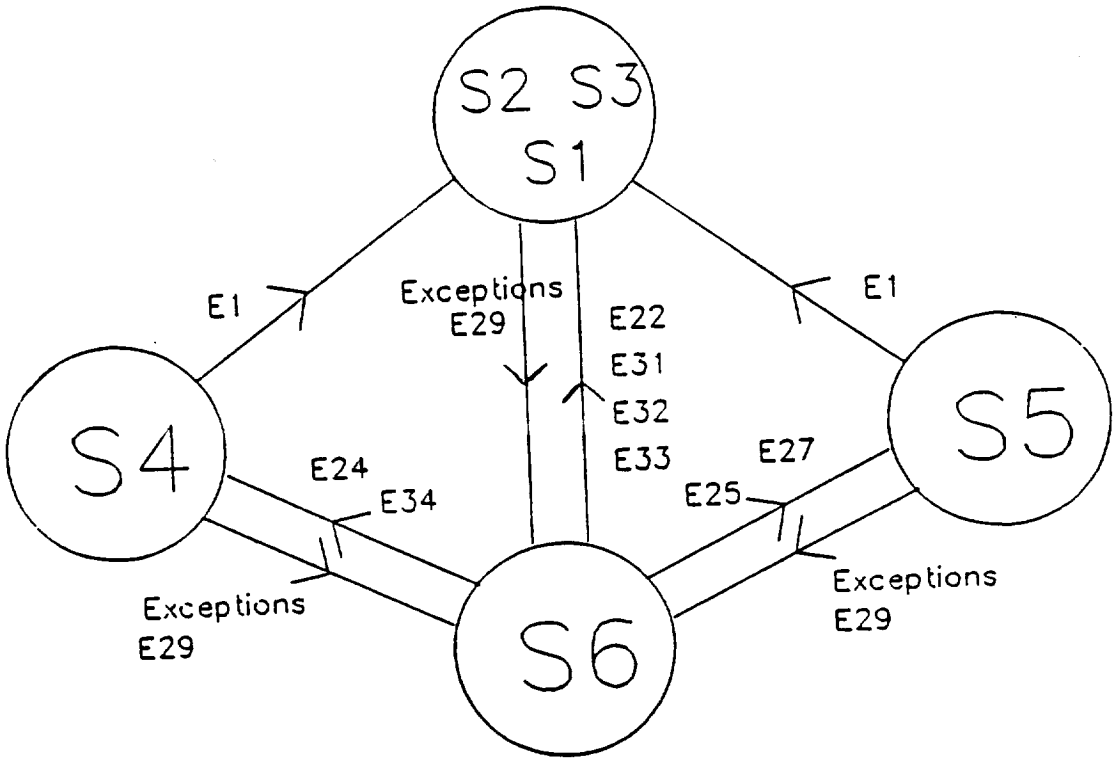


Figure 3.5 FOP-1 State Transitions

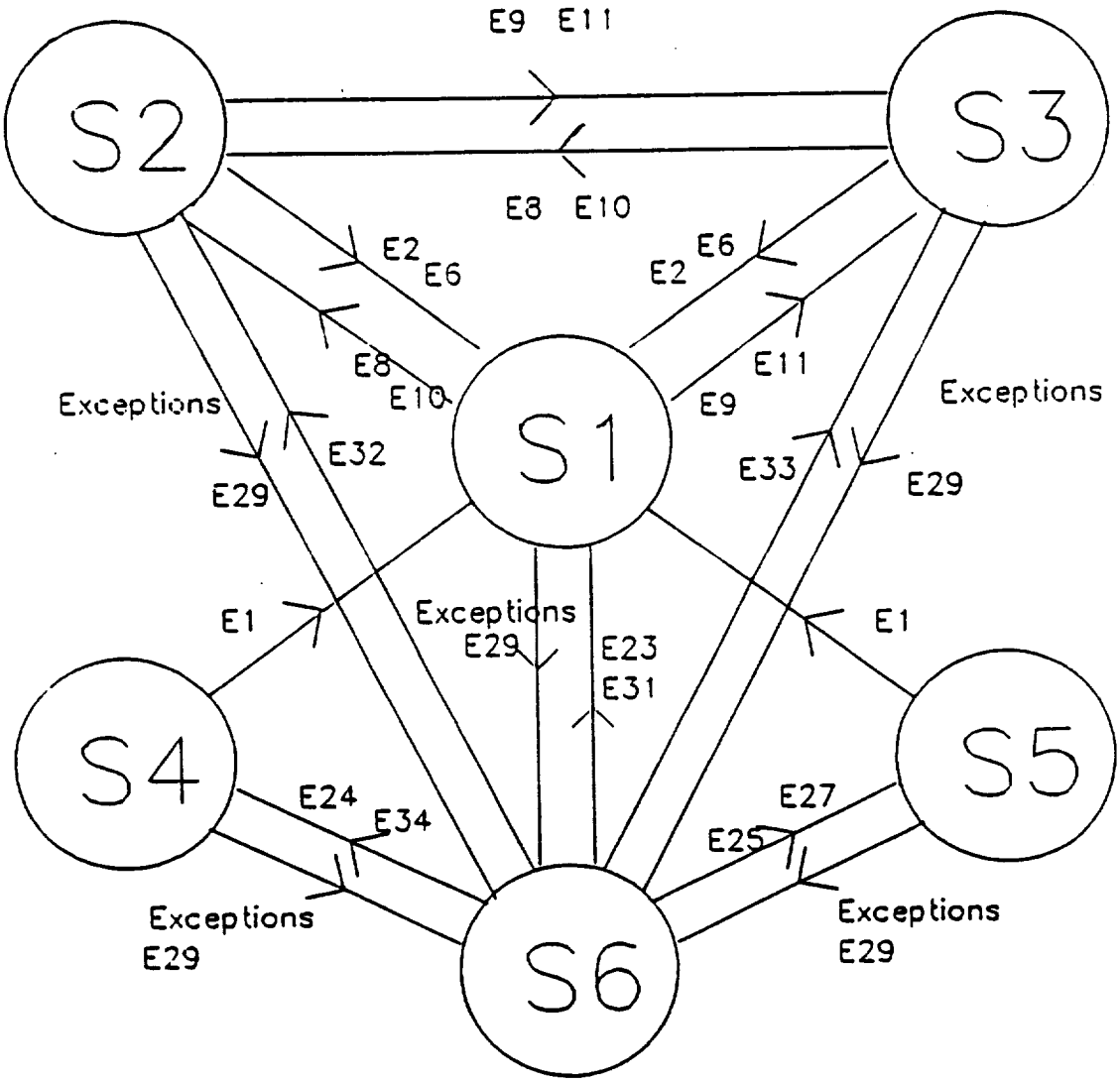


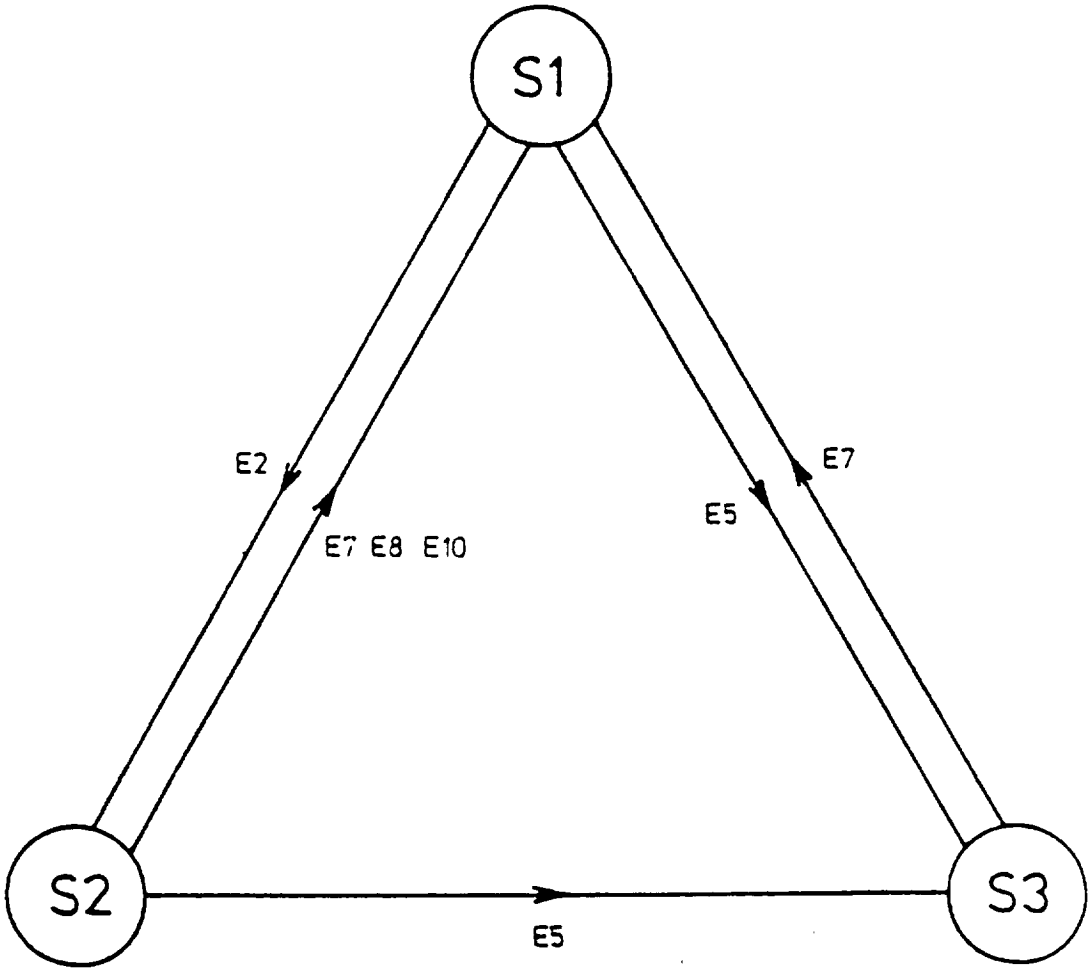
Table 3.2 FARM-1 State Table (Part 1)

State Name				OPEN	WAIT	LOCKOUT
Main Feature of State				Normal state to accept frames	Wait_Flag is on	Lockout_ Flag is on
State Number				S1	S2	S3
Event Conditions			Event Number			
Valid User Data type AD frame arrives	N(S)=V(R)	A buffer is available for this frame	E1	Accept frame, V(R) := V(R)+1, Retransmit_ Flag := 0 (S1)	Not applicable	Discard (S3)
		No buffer is available for this frame	E2	Discard, Retransmit_ Flag := 1, Wait_Flag := 1 (S2)	Discard (S2)	Discard (S3)
	N(S)>V(R) and N(S)<=(V(R)+PW-1) ie inside positive part of sliding window and N(S)<>V(R)		E3	Discard, Retransmit_ Flag := 1 (S1)	Discard (S2)	Discard (S3)
	N(S)<V(R) and N(S)>=(V(R)-NW) ie inside negative part of sliding window		E4	Discard (S1)	Discard (S2)	Discard (S3)
	N(S)>(V(R)+PW-1) and N(S)<(V(R)-NW) ie outside of sliding window		E5	Discard, Lockout_ Flag := 1 (S3)	Discard, Lockout_ Flag := 1 (S3)	Discard (S3)

Table 3.2 FARM-1 State Table (Part 2)

State Number			S1	S2	S3
Valid User Data type BD frame arrives	E6		Accept, Increment FARM-B_ Counter (S1)	Accept, Increment FARM-B_ Counter (S2)	Accept, Increment FARM-B_ Counter (S3)
Valid Unlock type BC frame arrives	E7		Increment FARM-B_ Counter, Retransmit_ Flag := 0 (S1)	Increment FARM-B_ Counter, Retransmit_ Flag := 0, Wait_Flag := 0 (S1)	Increment FARM-B_ Counter, Retransmit_ Flag := 0, Wait_Flag := 0, Lockout_ Flag := 0 (S1)
Valid Set V(R) to V*(R) type BC frame arrives	E8		Increment FARM-B_ Counter, Retransmit_ Flag := 0, V(R) := V*(R) (S1)	Increment FARM-B_ Counter, Retransmit_ Flag := 0, Wait_Flag := 0, V(R) := V*(R) (S1)	Increment FARM-B_ Counter (S3)
Invalid frame arrives	E9		Discard (S1)	Discard (S2)	Discard (S3)
Buffer release signal	E10		Ignore (S1)	Wait_Flag := 0 (S1)	Wait_Flag := 0 (S3)
CLCW Report Time	E11		Report value of: V(R), Lockout_ Flag, Wait_Flag, Retransmit_ Flag, FARM-B Counter (S1)	Report value of: V(R), Lockout_ Flag, Wait_Flag, Retransmit_ Flag, FARM-B Counter (S2)	Report value of: V(R), Lockout_ Flag, Wait_Flag, Retransmit_ Flag, FARM-B Counter (S3)

Figure 3.6 FARM-1 State Transitions



4 COP-2

TBS

ANNEX A

GLOSSARY OF ACRONYMS

This Annex is part of the Recommendation.

ANNEX A

GLOSSARY OF ACRONYMS

AD, BD, BC: These abbreviations reflect the state of the "Bypass" and "Control Command" flags in the Transfer Frame Header:

* Bypass Flag = 0 = A = Acceptance Check
* Bypass Flag = 1 = B = Bypass of Acceptance Check

* Command Control Flag = 0 = D = Data
* Command Control Flag = 1 = C = Control

It should be noted that only AD, BD and BC are legal: AC is an illegal combination since Control Commands cannot reliably use a transfer service which they are meant to modify. (Detailed definition of these flags is provided in Reference [3])

ARQ: Automatic Request for Retransmission

CLCW: Command Link Control Word (defined in Reference [3])

CLTU: Command Link Transmission Unit (defined in Reference [2])

COP: Command Operation Procedure

FARM: Frame Acceptance and Reporting Mechanism

FDU: Frame Data Units; the user data to be conveyed in a single frame

FOP: Frame Operation Procedure

ID: Identifier

K FOP_Sliding_Window_Width (FOP-1 variable)

LLIF Lower Layer Interface

N(R) FARM-A-Counter value (COP-0) or current observed value of FARM-1's Next Expected Frame Sequence Number V(R) (COP-1) from the current CLCW.

NN(R) The value of N(R) from the previous CLCW on that Virtual Channel. Denoted "Expected_Acknowledgement_Frame_Sequence_Number" by COP-1.

N(S)	The value of the Frame Sequence Number in the Telecommand Transfer Frame Header.
NW	FARM_Negative_Window_Width (FARM-1 variable)
PW	FARM_Positive_Window_Width (FARM-1 variable)
S/C:	Spacecraft
SS	Suspend_State. (FOP-1 variable)
TC:	Telecommand
TM:	Telemetry
TT	Timeout_Type. (FOP-1 variable)
T1_Initial	The initial value to which the countdown Timer is set. (FOP-1 variable)
VC:	Virtual Channel
V(R)	Receiver_Frame_Sequence_Number. The value of N(S) expected to be seen by FARM-1 in the next Type AD frame on the Virtual Channel.
V(S)	Transmitter_Frame_Sequence_Number. The value of the Frame_Sequence_Number, N(S), to be assigned by FOP-1 to the next Type AD frame to be transmitted.
W	FARM_Sliding_Window_Width (FARM-1 variable)